



DuboCalc

Designing a guideline to improve the accuracy and efficiency of DuboCalc

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Preface

After three years of studying civil engineering, I am finishing my bachelor's with the research: designing an additional guideline for DuboCalc (Duurzaam Bouwen Calculator). I did this research at Witteveen + Bos, who I want to thank for giving me this opportunity of researching this interesting, important, and currently hot topic. I wish Witteveen + Bos the best of luck in receiving the contract for managing and developing DuboCalc. This program has much potential that still has to be released. Good luck with making the world a greener place!

I want to thank the people that helped me in my research. From Witteveen + Bos, I would like to thank Stephanie for the feedback and constructive criticism during the meetings and for helping me find an interesting assignment in the first place. I would also like to thank the employees which helped me with the interviews: Cis Huinink, Ronald Hendriks, Dieuwertje Roelofsen, Wouter ter Heijden en Bas Roelofs. From the University of Twente, I would like to thank Marc van Buiten for guiding my research in the right direction and giving me the feedback I needed to successfully complete this research.

I sincerely hope my research can contribute to making the world a greener place and will help Witteveen + Bos.

Boris Staarman, Enschede, 04-07-2022

Abstract

DuboCalc is a program to quickly calculate the environmental costs of design variants of civil engineering works, expressed in a Milieu Kosten Indicator (MKI) value. The underlying goal is to stimulate sustainable innovations in the soil- water- road construction sector (GWW sector) in the Netherlands, to meet the climate goals set by the climate summit in Paris 2015. This research is commissioned by Witteveen + Bos, who experience challenges with the program. This leads them to believe that the MKI values are inaccurate and vary when calculated by different persons. This undermines the goals of researching sustainable solutions for civil engineering projects and comparing MKIs of projects in a fair way. For this research, two of the issues that users experience with DuboCalc will be researched, and a standardized method for solving them will be explored.

The report aims to develop a guideline that helps the users of DuboCalc with two challenges to improve the accuracy and efficiency of DuboCalc. The research question is: How can a guideline be designed which goal is to improve the accuracy and efficiency of DuboCalc?

To reach the goals of this research in a structured manner, the research will answer four sub-questions, after which the main research question will be answered. The first sub-question identifies the causes of the scaling product problem using interviews and literature. In the second sub-question, three methods of solving the challenges faced when scaling products are developed based on researching DuboCalc and literature review. In the third sub-question, the missing product problem will be researched, starting with identifying the causes of the problem by interviewing users of the program, case studies, and literature reviews. In the fourth sub-question, four methods are developed for dealing with missing materials based on literature review and interviews.

The results of the scaling product problem. The general conclusion is that products with functional units m, m², or piece cause problems because they can scale in different dimensions than their functional unit. Products with functional units kg, m³, hour, km, kWh, and tkm are not challenging to scale. The main cause of the problem when scaling products is the lack of information available on products. Examples of products in the national environmental database (NMD) are used to prove scaling is currently not done accurately. Accuracy loss when scaling products happens due to products, phases, or elements scaling disproportionately with regard to the 'main' product. Besides, the scaling can be done differently depending on the MKI executor, increasing the margins of error between different MKI executions. Two methods are developed to reduce the accuracy loss when scaling products. A third method is developed for when the other two methods cannot be used. The three methods are integrated into a flowchart to serve as a standardized method for scaling products. The MKI executor can use the flowchart to decide which scaling method to use. To help the users, additional elaborations of the choices to make in the flowchart are given, and the scaling methods are presented.

The results of the missing product problem. No unambiguous conclusion can be drawn about which materials are precisely missing but in general, specific materials not used often in the GWW sector or by Rijkswaterstaat are missing from the NMD. Many materials and products that are (or will be) used in the circular construction industry are not available in the NMD. This mainly concerns biobased and recycled materials and is important for encouraging sustainable engineering. Not many companies' products are included in the NMD. This is because quite some effort and money goes into getting a product's Life Cycle Analysis (LCA) approved. Four methods are developed to work around the missing product problem. The four methods are: searching for an alternative product, calculating the LCA with another program, making an estimation based on another data source, and outsourcing the LCA calculation. These methods are not long-term solutions to the problem. A recommendation is to integrate the data from the European databases conforming to the EN15804, which is a European norm for the life cycle assessment of products in the construction industry.

No unambiguous method for the problem of scaling and missing products is found. For both challenges, multiple methods are developed to help users of DuboCalc. The report ends with recommendations on how to continue this research and recommendations on how to improve DuboCalc. Overall, the research addresses the challenges of the program and mentions methods to improve the accuracy and efficiency of DuboCalc.

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1. Introduction

1.1. Context

In 2015, a climate conference took place in Paris, the 195 participating countries agreed to a binding climate agreement in the battle against global warming. This agreement aims to reduce the emission of greenhouse gasses and limit global warming to 2 degrees with a target value of 1,5 degrees (Europa Nu, 2018). The first target is reducing the CO₂ emissions in 2030 by 40% with respect to 1992. In April 2018, the European Parliament agreed to new climate legislation to decrease the emission of greenhouse gasses in the construction industry each year. The Dutch construction sector is responsible for 11% of the national CO₂ emissions yearly (Bosch, Anink, & van Leeuwen, 2022). For this reason, sustainability in the construction industry is of great importance.

Rijkswaterstaat has developed a method to test the environmental impact of construction works in the soil- water- road construction sector (GWW sector). This method calculates an environmental cost indicator (MKI), which is a fictive value expressed in euros and indicates the environmental costs of a project. This MKI consists of eleven different impact categories, of which CO₂ emissions contribute to about 50% of the environmental impact (Klauw, 2018). The MKI consists of Life Cycle Analysis (LCA) scores of all products and processes used in the project. The MKI score represents the product's environmental impact over its entire life cycle, from cradle to cradle. This MKI is calculated by Duurzaam Bouwen Calculator (DuboCalc), which is a program prescribed by Rijkswaterstaat and developed by Cenesco and Royal HaskoningDHV (DuboCalc, 2022). The program uses the National Environmental Database (NMD) as its input data for calculating MKIs. In the tender phase of all GWW works in the Netherlands, the MKI is an important factor. Engineering companies receive a fictitious discount for the MKI of a project. A low MKI will result in a high fictitious discount, which improves the chance of receiving a project's contract. The goal of Rijkswaterstaat is to encourage the market to innovate in sustainable construction and build sustainable to reach the goals set by the climate summit in Paris. The MKIs of different projects can be compared, but there is a lot of freedom in the method. A research by Levels-Vermeer, van Ewijk, Scheepmaker, & de Vries (2015) concluded that the differences in environmental impact over the entire life cycle with regard to the reference situation caused by allocation differences are a maximum of 50% in the reuse, recovery, and recycling phase of the material. This is a problem since the MKI value should be a fair comparison tool for tenders.

This research is commissioned by Witteveen + Bos, an engineering firm in the construction industry based in the Netherlands. Witteveen + Bos is involved with projects worldwide and "focuses on finding sustainable solutions for the challenges of these times" (Witteveen + Bos, sd). Witteveen + Bos experience challenges with DuboCalc, which is why this research is conducted. Increasingly more construction companies like Witteveen + Bos want to become more sustainable and ask for an unambiguous measuring method (Bosch, Anink, & van Leeuwen, 2022). This measuring method DuboCalc is obligatory to use in the GWW sector but does not function as it should. This research is conducted to study two challenges the users of DuboCalc face and try to improve the MKI determination process. Witteveen + Bos is currently in the tender phase for maintaining and managing DuboCalc. This project can serve as a preliminary investigation for when DuboCalc is under management by Witteveen + Bos.

1.2. Problem statement

Witteveen + Bos face two challenges calculating MKIs using DuboCalc, which leads them to believe the resulting MKIs contain inaccuracies and are time inefficient. This problem goes against the purpose of DuboCalc, a tool used to compare MKI scores. The first problem with DuboCalc is the scaling of products. The quantity of a product is adjustable, but the functional unit is fixed. When the product has to be scaled, all life cycle stages of a product are scaled proportionately, which can cause flawed LCA values. The second problem is the availability of parts and products in the NMD. Not all products in the GWW sector are available in the NMD, which can be a problem. Should a product be chosen with similar material but different size, or same size and different material? For both challenges, no standardized method is available on how to deal with this challenges. The MKI is very dependent on the MKI executor which can cause uneven MKI calculations and unfair scores.

In conclusion, Witteveen + Bos experiences challenges with the scaling and missing products in DuboCalc, which cause inaccuracies and time loss when executing MKIs. There is no standardized method for these challenges, which can cause uneven results in MKI calculations.

1.3. Research aim

This research aims to design an additional guideline that improves the accuracy and efficiency of DuboCalc. The research will try to reach these goals by developing an additional guideline for DuboCalc to focus on two challenges.

There is a lack of clarity on what to do when a product required is not the right size in the NMD. A standardized method will be developed for all product scaling challenges. The same counts for the missing product problem. A standardized method will be developed and integrated into a guideline to help the MKI executor solve the problem. This is to help reach the goals of Rijkswaterstaat regarding DuboCalc, which is to have an accurate and fair MKI measuring method.

This research will also serve as an exploratory research. Witteveen + Bos is currently in the tender phase for the management and development of DuboCalc. This report can serve as an investigation base by researching the flaws and possibilities of DuboCalc.

1.4. Research question

Four sub-questions are set up to reach the desired goal. The goal of this research is to design an additional guideline for users of DuboCalc that aims to assist the users in making choices when dealing with challenges and to improve the accuracy and efficiency of DuboCalc. The main research question is:

How can a guideline be designed which goal to improve the accuracy and efficiency of DuboCalc?

Two program issues will be researched in four sub-questions. How these sub-questions will be researched will be explained in the following chapter. The first sub-question is:

1. What are the causes of the scaling product problem?

After the causes are stated, a standardized method of solving the problem can be researched in the second sub-question.

2. What is a standardized method of solving the scaling product problem?

- 2.1. What influence has scaling on the margins of error?
- 2.2. What are methods of countering the causes?
- 2.3. What are the methods of scaling products?
- 2.4. What is the best method of writing a guideline?

The research for the second problem can begin, starting with the following question.

3. What are the causes of the missing product problem?

The cause is stated. Now, a standardized method of dealing with the problem will be researched.

4. What is a standardized method of solving the missing product problem?

- 4.1. What are possible methods of dealing with missing products?
- 4.2. How can these methods be used optimally?

Then, the solutions to sub-question 2 and 4 are integrated into a guideline to finalize the research and answer the research question.

1.5. Methodology

This chapter explains the research methods. All sub-questions and their research methods will be discussed to explain how the research question will be answered.

1.5.1. Sub-question

What are the causes of the scaling product problem?

First, the MKI determining process is mapped with a literature review. Documents, guidelines, and videos of Rijkswaterstaat, DuboCalc, and Royal HaskoningDHV will be researched on how to use DuboCalc according to its developers. Next to that, the program will be researched by using it. The second step in determining the causes of the product scaling problem is interviewing experts. Interviews with employees of Witteveen + Bos who use DuboCalc regularly will be held in a semi-structured interview and analyzed.

1.5.2. Sub-question 2

What is a standardized method of solving the scaling product problem?

The second sub-question aims to find solutions for the product scaling problem and design a standardized method of dealing with them. First, a distinction in the method will be made about the required MKI accuracy of the guideline.

Interviews are held to determine the current existing methods of dealing with the scaling product problem. The users of the program deal with the problem for quite some time now so they will have much useful input. In addition, literature research will be done on additional methods of scaling products. LCAs of products will be researched for scaling, together with products in the NMD. Together with reviewing the literature, methods to deal with scaling issues will be developed and integrated into a guideline. For this, developing a guideline will be researched. The guideline should meet the following requirements:

- The guideline should cover the complete problem-solving process.
- The guideline should be easy to use, straightforward, and used without any required foreknowledge.
- The method should not be difficult to use.
- The method should be future proof, it needs to be adjustable. The rules and method of the MKI determination system and DuboCalc change which requires a flexible method.

1.5.3. Sub-question 3

What are the causes of the missing product problem?

Interviewing experts in a semi-structured interview will be the base for researching this question. Question will be asked about which products they missed in the database in past projects. The missing materials must be grouped to find a possible correlation between them. Since the interviewees cannot give all the answers, cases and projects within the GWW sector will be studied. The case studies provide background knowledge for how Witteveen + Bos calculates MKIs. Literature will be reviewed to research what other parties think of the problem.

1.5.4. Sub-question 4

What is a standardized method of solving the missing product problem?

The fourth sub-question aims to develop a standardized method for the missing product problem. Semi-structured interviews will be conducted to see how the users currently deal with the challenges. From foregoing research, two methods of dealings with missing products are known which will be researched. Depending on the methods from the interviews and foregoing research, additional research will be done on how to scale products.

1.5.5. Research question

How can a guideline be designed which goal to improve the accuracy and efficiency of DuboCalc?

The standardized methods developed in the sub-questions must be implemented in the guideline. During the interviews, questions about what the employees want to see in the guideline will be asked. The interviewees' opinion will be taken into account here since they have a solid and clear say about the current flaws of the method. The answers will be kept in mind while designing the guideline. Follow-up research and recommendations about the MKI determination system will be made, mainly about DuboCalc and the NMD. These are based on own findings during the research and on literature research.

1.5.6. Qualitative interview

Five employees of Witteveen + Bos who are regular users will be interviewed about DuboCalc. The elaborations can be found in the appendix Interviewing experts. The interviewees have not used DuboCalc for longer than eighteen months with a minimum time of six months. The interviewees used DuboCalc in different settings but with the same end goal, to calculate MKIs and reduce the environmental impact of civil engineering projects.

The interview consists of three parts. The first part is about scaling products. The second part is about the missing materials. The third part discusses the research in general and the deliverable. The following questions are asked:

- 1) Scaling products
 - a) What kind of projects do you do most in the GWW sector?
 - b) Do you recognize the problem of scaling products in DuboCalc, and if yes, how are you solving them?
 - c) At which products do you experience these challenges?
 - d) Does it depend on the functional unit that products are hard to scale?
- 2) Missing products
 - a) Do you recognize the problem that products are missing from the NMD, and if yes, how are you solving them?
 - b) At which products do you encounter these challenges most?
- 3) Research and deliverable
 - a) What would you like to see in an additional manual?
 - b) Do you have any more tips for my research?

1.6. Reading guide

For clarification of this report, the general structure is explained in short. In the previous chapters, the context of this research, the problem statement, the research aim and questions, and the methodology are stated. Now, the research design should be clear. The following four chapters present the research results. The first sub-question deals with the cause of the scaling product problem. The second sub-question contains the research on a standardized method of scaling products and the results. Then, the third sub-question discusses the cause of the missing products. Then, the fourth sub-question researches the standardized method of dealing with missing products. Then, the discussion, the conclusion, and the recommendations that came up during this research are presented.

2. The scaling product problem

The scaling product problem arises when a product required for the MKI calculation is not the right size in the NMD. This chapter researches the cause of the problem of scaling products. First, the interviews are analyzed. Then, DuboCalc and the NMD have been researched to answer the question: what are the causes of the scaling product problem?

2.1. Interviews

All interviewees agreed that scaling in DuboCalc is a problem. The first and leading problem is the lack of information available on the products. All products have a general description and it is not mandatory by the NMD to include information on the product. Too little information causes challenges. 92% of the products are from category three. Category three is generic data which is based on the database Ecoinvent, which is the “publisher of the world’s most consistent & transparent life cycle inventory database” (Ecoinvent, sd). This data gets an additional increase on its MKI value of 30% because experience shows that untested environmental profiles often indicate too low of an environmental impact. Category one is proprietary data products and category two is unbranded data, which are both tested by an independent qualified third party according to the NMD testing protocol. Generally, products from category three have less information than those from categories one and two. No clear relation to what types of products cause the problem, but it depends on the functional unit. According to the interviewees, the following products cause problems: beams, tubes, foundation piles, pipes, light poles, geo-textile, and sheet piles. Products with fixed dimensions give problems when this product is needed with different dimensions. The general conclusion is that the functional units m, m², or piece are difficult to scale because these products can scale in all three dimensions. The products with functional units kg, km, m³, hour, kWh, and tkm can only scale in the same dimension as their functional unit, which causes no scaling problems. The second cause of the scaling problem is that there is no standardized method by Rijkswaterstaat or any other instancy. The MKI executors have to determine for themselves what to do in case a product needs to be scaled.

Witteveen + Bos is currently in the tender phase of the management and development of DuboCalc in combination with an external software developer (Hendriks, 2022). For that reason, an extensive recommendation on how to improve DuboCalc would be useful. The developers of DuboCalc are currently working on a scaling function for DuboCalc 6.1, so this will probably be implemented soon (Aardenburg, 2022). However, missing information is still a big problem that cannot easily be fixed. A reason is the secrecy and sensitivity of data from category one that companies are unwilling to share.

2.2. Example information availability

This insufficient availability of information declared by the interviewees can raise questions when comparing similar products with very different MKI values. An example of this is aluminum light posts. The specifications of three light posts in the NMD are stated in Table 1.

Table 1: specifications of three light posts

Product name	lifespan	description	MKI per FU
light pole in neighborhood, aluminum 4 meter (piece)	30	It concerns an aluminum light pole of 4 m. The aluminum light pole is placed in a residential area.	8,84
light pole, aluminum, 4 meter (piece)	30	T4m alumn single bracket, length 4800/800 underground, clear sanded without coating. 4/6m most commonly used in neighborhoods. NE2 crash class. 12kg. Min 50-75% recycled aluminum. Only A1-A3 available.	14,8
light pole aluminum scalable	30	Light pole of 4 meters. Scalable to length from 4 to 18 meters. Only the material scales, the processes for placing and removing are fixed	6,96

(piece)		values.	
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At first sight, these are three aluminum light posts with a length of 4 meters. The description does not clarify much either, only the MKI differs much. When an MKI executor needs an aluminum light post, they would probably select the one with the lowest MKI, although that could not be accurate.

2.3. Scaling

Table 2 shows the functional unit products can have in DuboCalc and the scaling options. Figure 1 shows graphically the ways products can scale. The functional units kg, hour, km, tkm, and kW can only be multiplied by their own dimension. The functional units kWh and tkm have two components that can be multiplied in their own dimension. The products m, m², m³, and piece have three dimensions that can be scaled.

Table 2: functional units and scaling options

FU	Dimensions of product	Scalable dimension of product	Proportionate scaling?
kg	1	1: kg	yes
hour	1	1: hour	yes
km	1	1: km	yes
kW	1	1: kW	yes
kWh	2	2: kW * hour	yes, the amount of product is the power for a number of hours, proportionate with both. 1 kW for 2 hours = 2kW for 1 hour
tkm	2	2: ton*km	yes, the amount of product is transport distance * weight of product. 1 ton over 2 km = 2 ton over 1 km
m ³	3	1: m ³	yes, the amount of product is volume of product required.
m ²	3	2: m ² & m ³	m ² → m ² is proportionate m ² → m ³ is disproportionate
m ¹	3	3: m ¹ & m ² & m ³	m ¹ → m ¹ is proportionate, m ¹ → m ² is disproportionate m ¹ → m ³ is disproportionate
piece	3	3: m ¹ & m ² & m ³	piece → m ¹ is proportionate, piece → m ² is disproportionate piece → m ³ is disproportionate

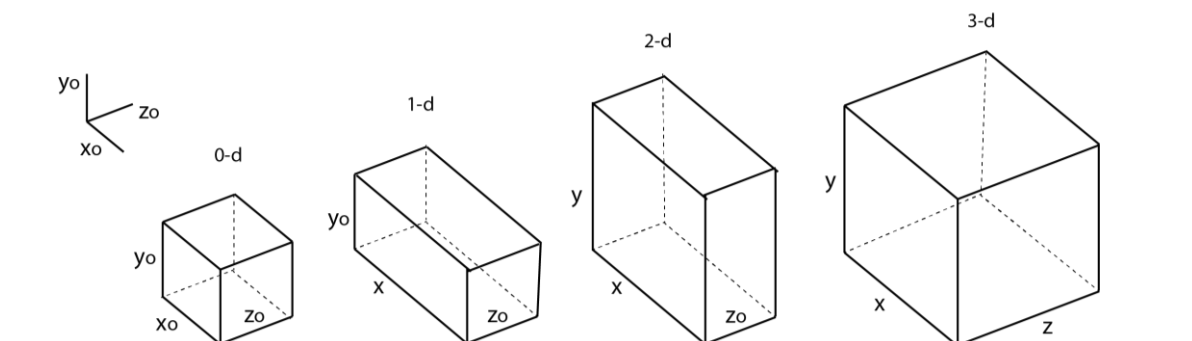


Figure 1: graphical explanation of the scalable dimensions

2.4. Conclusion

The general solution of the interviews is that the problem of scaling products is caused by two problems. The first is missing information from the NMD. Products with functional units m, m², or piece cause problems because they can scale in different dimensions than their functional unit. Products with functional units kg, m³, hour, km, kWh, and tkm are not causing problems when scaling. The graphical explanation can be found in the Figure 1. The second problem is a missing scaling method. No standardized method is available for what to do when a product needs to be scaled in DuboCalc, this is up to the MKI executor to determine. Confusion during scaling products can happen due to little information available on products. This makes it hard for the MKI executor to scale the product to the correct size.

3. Standardized method for the scaling problem

In this chapter, the methods of scaling the products will be researched. Based on the literature, three methods of scaling are researched. First, margins of errors when scaling will be researched with products in the NMD. With these examples, the hypotheses that certain phases, elements, and dimensions do not scale proportionately with regard to the 'main' product will be researched. Then, the methods of reducing these errors are researched. Then, a final method is developed when all other methods cannot work. A guideline is created to choose between the methods, which results in a standardized method for scaling products to answer the sub-question: what is a standardized method of solving the scaling product problem?

3.1. Margins of errors when scaling products

Three ways scaling could go wrong in an MKI determination are explained with examples from the NMD. These examples show how inaccuracies in scaling can happen. The examples are chosen since they represent everyday examples of scaling in DuboCalc. All examples contain volumes, elements or phases scaling disproportionate to the 'main' product, which is the product or action of the card, stated in the title. Five examples will be presented, the elaborations are stated in the appendix Margins of errors when scaling products.

3.1.1. Disproportionate scaling

Disproportionate scaling happens when a product scales one parameter, length, width, or depth, and the volume/weight of the product does not scale proportionately with that parameter. Inaccuracies occur because the parameter scales proportionately in DuboCalc while does not in real life. An example of this is a light pole with a length of 4 meters weighs 23 kg (SpeciShops, sd). The same light pole, but with a length of 6 meters, weighs 45 kg. A length increase of 1.5 times comes with a weight increase of 1,96 times. This shows that the material used in light poles does not scale proportionately with the length and thus also the MKI.

3.1.2. Element or phase scaling

According to Lex Roes, a certified LCA specialist, the environmental impact of the maintenance of a bridge does not necessarily scale proportionally to its length. "You would have to estimate the scale the maintenance impact increases with regard to the distance" (Roes, 2022). Research is done on how different phases of products scale. Products in DuboCalc can consist of multiple elements that can serve as tools, processes, and sub-products. Research will be done on how these elements scale with regard to the main product. On the other hand, products in the NMD can also consist of one element. For these products, research will be done on how the different life cycle phases scale. First, elements scaling will be researched with two examples, then phase scaling with two examples.

Element scaling: weir valves

The first example from the NMD is three weir valves. These are the same products but with different dimensions and thus different MKIs. The products consist of two elements, the weir valve, and a crane. The crane contributes the same MKI value to all three products even though the weir valves differ in size. The percentage of MKI contribution of the crane is different for each wire valve, and the MKI impact of the crane scales disproportionately to the main product.

Element scaling: interior door

The second example is an "interior facade; frame and door". This product contains a hinge as an element contributing to 21.5% of the MKI (DuboCalc, 2022). When a door is needed half its size, the MKI executor can take 0.5 of the interior door. Then, the MKI contribution of the hinges get halved too, while this would not be true because a door cannot function on half its hinges. A door that is a bit smaller needs as many hinges as a bigger door. The hinges do not scale proportionately with the door size, while this would be the case in DuboCalc.

Phase scaling: bridges

The first disproportionate phase scaling example consists of four bridges. The researched phase is the use phase containing the maintenance, repairs, substitutions, and renewal phase during the life cycle of a bridge. The NMD contains two steel bridges, one with a span of 15 meters and one with a span of 160 meters with a respective MKI impact of 35,1 and 37,5 MKI per meter bridge for the use phase. Oddly, these MKI per use phase of the steel bridge correspond. One would expect that the width of a bridge that is 160 meters instead of 15 meters would be much larger, and a more significant difference in MKI use phase per meter bridge would be observed, which is not the case. The NMD also contains two concrete bridges with a span of 6 meters and a span of 15 meters. The MKI of the use phase per meter bridge is respectively 56,7 and 33. This is a large difference in the use phase of two small concrete bridges.

Phase scaling: inspection pit prefab concrete

The last example consists of three prefab (prefabricated) inspection pits. The volume of the product has been plotted against the MKI of the product and the MKI of process C1 (demolition). Both do not scale proportionately. The best-fitting line for both graphs is a power function. The volume against MKI product has a power < 1 . The volume against MKI C1 has a power > 1 . This means that as the volume of the product increases, the MKI of the demolition process has less impact and the MKI of the 'main' product has relatively more impact.

3.2. Methods of reducing margins of errors

Two methods of reducing the margins of errors will be explained. The first method is developed to counter the disproportionate scaling, the second method will counter the disproportionate element and phase scaling.

3.2.1. Disproportionate scaling

"De toepassing van de schalingsformules in de NMD 3.0" is a guideline for implementing scaling formulas for new products in the NMD (Stichting Nationale Milieudatabase, 2021). This method is prescribed by Rijkswaterstaat for adding a product to the database, on which this method is based. This is considered the primary method because it is developed and prescribed by Stichting Nationale Milieudatabase, who are the managers of the NMD. The method should be used when a dimension of a product does not scale proportionally to its weight or volume, which can only happen at products with a functional unit m, m², or piece (Loos, 2011). The method aims to find a relation between the size of the product, the scaling factor, and eventually the MKI. An example of the method is in the appendix Example disproportionate scaling method. The method consists of four steps:

1. Determine the scalable dimension. Which dimension of the product is scaled with regard to the volume/weight. This can be length, width, depth, or diameter.
2. Create a table with product variants (measurement points). Make a table in which the scalable dimension and the associated volume/weight are plotted for several variants. Use at least three variable measuring points, so three masses with the associated scalable variable.
3. Insert the data in Excel and use the trendline function in Excel to determine the best fitting graph.
 - a. Perform an R² test. The R² score (graph option in Excel) can aid in determining the best-fit line. The R² test determines how well a regression model fits a dataset. The closer the R² score approaches 1, the better it is. Values lower than 0.9 indicate a poor fit.
 - b. Some graphs are more accurate at high or low scaling sizes, which can be derived from the graph. Compare this with the required scaling size in determining the best fitting graph.
4. Use the scaling function to determine the MKI. A function of the mass and the scalable dimension is created. The formula that Excel displays can be used to calculate the weight at a particular scalable dimension. With the weight and the MKI of the original product, the MKI weight ratio of the product can be calculated. This ratio can be used to determine the new MKI of the scaled product. Depending on the functional unit, the MKI must be integrated into the MKI calculation.

3.2.2. Element and phase scaling

As shown in the examples, some elements or phases do not scale proportionally with the size of the product. This method is developed by the author and based on flaws in the current scaling method. Many elements in the NMD behave differently, meaning a standard rule for element scaling cannot exist. The idea of phase and element scaling relies on the fact that phases or parts (products) of the life cycles do not scale proportionately with the size of the 'main' product. The main product is considered to be the object mentioned in the product's title, generally containing the production phase (A1-A3). The aim is to find a relation between the part or process that does not scale proportionally with the main product, which is up to the MKI executor to determine. The products or parts to consider for element or phase scaling generally contain one of the elements or phases stated in Table 3.

Table 3: processes, parts, and phases to consider for element or phase scaling

tools (per hour)	concrete mixer	wheel loader	(tele) crane	tractor	bulldozer	demolition
	concrete pump truck	pile driving	surface treatment	reuse	construction	excavator (with sledgehammer)
products (pieces & m²)	reinforcement	fasteners	concrete mortar	slope	hinges	
phases	A5 construction and installation	B1-B5 use and maintenance	C1,C3,C4 demolition and processing			

Use method one preferably. Use method two when not enough information is available for method one.

Method 1

A formula will be set up which calculates the MKI of certain elements or phases with respect to the main product volume, size (1 dimension), or weight. Now, the product can be scaled to the right volume, size, or weight, and the MKI impact of the elements or phase can be calculated. EPDs (Environmental Product Declaration) of the same product need to be analyzed to prove that a particular element or phase does not scale proportionally. The products or parts to consider for element or phase scaling are stated in the Table 3.

1. At least three reference data points need to be known of the product's volume, size, or weight in relation to the MKI of the element or phase. Information gathering can be done with products in DuboCalc, using the internet searching for the same product, or using alternative data sources.
2. Plot the three data points of the weight/volume and MKI of the scalable element or phase in Excel.
3. Use the trendline function in Excel to determine the best fitting graph.
 - a. perform an R^2 test
 - b. Some graphs are more accurate at high or low scaling sizes, which can be derived from the graph. Compare this with the required scaling size in determining the best fitting graph.
4. If the best fitting trendline is the linear function, this method should not be used, and the 1,2, or 3-dimensional scaling should be used.
5. Fill in the volume, weight, or size of the scaled product, and the MKI value of the element that scaled disproportionately is the result.
6. Compare the results of the element MKI calculated with Excel and the element MKI calculated by DuboCalc. Conclude and if applicable, integrate the difference in the MKI calculation.
 - a. This can be done by calculating the MKI with the adjusted element and scaling the product in DuboCalc to match the new calculated MKI.
7. Substantiate and elaborate on the choices so that others can understand what is done.

Method 2

This method uses another information source to determine how the element or phase scales with regard to the main product. Depending on the product and the elements, they may or may not scale disproportionately. This is up to the MKI executor to judge and to research. Table 3 states widely used examples of elements and phases that may not scale proportionately with the product. This method is more open for the MKI executor. Information on how the element or phase scales with regard to the volume, weight, or size of the main product has to be found. Depending on the product, this can be done in various ways. Information sources to use.

- Researching LCA or EPD of similar products
- Data category one: contact the product data owner
- Data category two: research branch representatives
- Data category three: contact Ecoinvent
- Search in one of the databases in Table 6 earlier mentioned this report

There are many ways elements can behave under different circumstances, the phases to consider are A5, B1-B5, C1, C3, and C4. Other points of attention to take into consideration are:

- Is the product scaling per functional unit or part product?
- How are the tools used? Is it per hour, per kg, or anything else that does not scale (proportionate)?
- Page 65-67 of the “Bepalingsmethode” contains extra information on what the phases of the EPD include exactly. This could be useful when determining if something should be considered.

When the elements and the MKI differences are analyzed and calculated, this needs to be integrated into DuboCalc. This can be done by calculating the new and old elements’ MKI difference and adding to the overall products MKI. Then the scale of the product can be adjusted to match the new MKI. At last, it is important to document the decisions made in the process. Substantiate and elaborate on the choices made in the process.

3.3. 1,2,3-dimensional scaling

When the other two methods cannot be used, this is a more straightforward method, developed by the author. The method is based on “De toepassing van de schalingsformules in de NMD3.0”. This method uses scaling formulas to calculate the scaling factor. A product's functional unit determines the number of dimensions it can scale in, with a maximum of three. Then, formulas are set up that calculate the scalable quantity in DuboCalc. This method uses the product’s dimensions relative to the original product. The formulas can be found in Table 4. Examples of how products scale in different dimensions are in appendix Scaling examples with functional units.

Table 4: scaling formulas with dimensions

	piece	m ¹	m ²	tkm	kWh	m ³	kg, hour, km, kW
1-d	Y = FU	Y = FU		Y = t Y = km	Y = kW Y = h		Y = FU
2-d (new m ² /old m ²)	Y = (x * y) / (xo * yo)	Y = (FU * y) / (xo * yo)	Y = FU	Y = ton * kilometer	Y = kW * hour		
3-d beam (new m ³ /old m ³)	Y = (x*y*z) / (xo*yo*zo)	Y = (FU*y*z) / (xo*yo*zo)	Y = (FU * z) / (xo*yo*zo)			Y = FU	
3-d pile/cylindre (new m ³ /old m ³)	Y = x * (π(R1 ² -R2 ²) / (π(R1o ² -R2o ²))	Y = FU * (π(R1 ² -R2 ²) / (π(R1o ² -R2o ²))					

In which x is length x in design, xo is original length x, y is length y in design, yo is original length y, z is length z in design, zo is original length z dimension of the product, R1 is outer diameter, R2 is inside diameter, R1o is outer diameter original product, R2o is inside diameter original product. FU is FU in the design, and Y is quantity in DuboCalc. Dimensions with names are in Table 4 and graphically presented in Figure 1.

3.4. Standardized method for scaling products

A flowchart is created for the decision-making process on which method to use, which can be found in Figure 2. The first choice is if they are in a project’s exploration or tender phase. Then, four decisions have to be made.

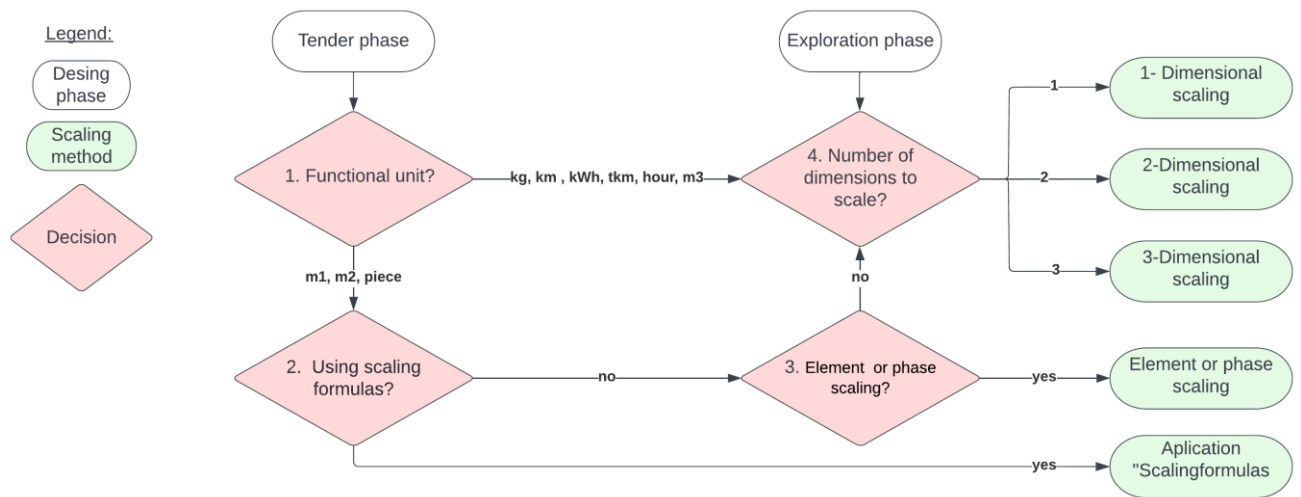


Figure 2: standardized method for scaling products

Decision 1: what is the functional unit?

This decision is straightforward. Choose the functional unit displayed in the product details in DuboCalc.

Decision 2: using scaling formulas?

Is there a suspicion that a dimension of a product: length, width, or depth, scales disproportionate to its weight, then scaling formulas need to be applied. When it turns out not to be the case, continue to decision three. The goal is to set up a formula that describes the relation between a dimension of the product and compare it to its weight or volume. Three data points are required to set up a function in Excel, as shown in the Example disproportionate scaling method. The requirements for this method are:

- A product's weight or volume scales disproportionately with regard to one of the following dimensions: length, width, or depth
- Other reference data of the product is available, which is the same product with other dimensions, regarding the weight or volume and the other scalable dimension

Decision 3: element or phase scaling, or neither?

The choice between phase or element scaling and neither depends on the data availability, the EPD, and the required accuracy of the MKI. This method is not time efficient, so a choice must be made if it is worth doing it. The method is based on the suspicion that phases or elements in a product's lifecycle do not scale proportionately to the size of the 'main' product. If this is not the case, continue to decision four. This choice is up to the MKI executor for each case-specific. The products or parts to consider for element or phase scaling are in Table 3.

Decision 4: what are the number of dimensions to scaled

Figure 1 can be used to determine in how many dimensions the product will be scaled: 1-dimensional scaling (kg, hour, piece, m, km, kW), 2-dimensional scaling (kWh, tkm, piece, m, m²), or 3-dimensional scaling (piece, m, m², m³).

3.5. Conclusion

Five examples of products are researched to prove that some parts of products, phases, or elements do not scale proportionately with regard to the 'main' product. To reduce the margins of errors when scaling products, two methods have been developed. These methods are not always applicable, which is why a third method is presented which can always be used. These methods are integrated into a flowchart to form a standardized method. The flowchart helps the MKI executor decide which of the three scaling methods to use. The first choice is to determine which phase the project is in, which determines the required MKI accuracy. Then, the flowchart can be followed, which can be found in Figure 2. The three methods of scaling are: disproportionate scaling, element or phase scaling, and 1,2, or 3-dimensional scaling. The MKI executor still has to determine which scaling method to use and how to address the problem, the guideline serves as an additional tool

4. The missing product problem

Problems occur when a product required for an MKI calculation is not available in the NMD. Before being able to solve a problem, the cause needs to be known. This chapter will research the causes of the missing product problem. The obvious problem, which products are missing, will be researched but also one layer deeper, why products are missing from the database. The interviews will be analyzed, cases will be studied, and literature will be reviewed to answer the sub-question: what are the causes of the missing product problem?

4.1. Experts interview

According to the interviewees, the following products cause the most problems due to the absence: steel sheet piles, stainless steel products, (steel) beams, tubes, several types of wood, soils, composite materials, polymers, and geotextile. Many basic materials used in the GWW sector, like steel or aluminum, are unavailable in the NMD. These materials are only represented in products. Products not used very often in the GWW sector have less priority and are less represented in the NMD. The common thread is that the major products in the GWW sector are available, but more specific products, and products that are not often used are not well represented.

The general conclusion is that products not well enough available are soils, metals, and specific products not often used by Rijkswaterstaat. The problem is enlarged by the lack of data available on the products. This causes MKI executors to guess the products' properties.

4.2. Case studies

The cases are studied for how the MKI executors deal with the missing products. Four studies contain information on all products used in the project. These products, with the corresponding DuboCalc product and the quantity used in the MKI calculation, are stated in the reports. The products contain remarks with specifications of the product and explain why a particular DuboCalc product has been chosen. The elaborations of the case studies can be found in the appendix Case studies.

Due to the changing NMD, it can happen that products missing in the meantime have been added or the other way around, that the lifespan of a product is finished and thus is removed from the NMD. Table 5 contains a list of the function of a product in a project, and the product from the NMD used in the MKI calculation. These are examples of products chosen for the MKI calculation based on assumptions.

Table 5: case study results, intended product function, and used DuboCalc product

Product function	NMD product based on assumptions
demolition and construction noise barrier	reinforced concrete noise barriers
removing light posts	light posts length 15 meter
adjusting artworks (objects)	quantity reinforcing steel of 150kg/m ³
all foundation layers used except the bicycle path	250 mm hydraulic mixing granulate
three coatings (AC 11, MODUS, DESA)	AC asphalt deklaag, (respectively 35, 30, 30 mm)
60 mm AC 16 base OL-IB & 60 mm AC 22 base OL-B	both used: AC bin base 50%PR cat. 2
Concrete C28/35 wet/dry-, defrost salts/ chlorides XD3	concrete mortar C30/37 (CEM I)
Asphalt AC 22 base O2 (STAB 0/22 vk 3 Dutch)	asphalt STAB 0 %
Terra Armee	Prefab concrete plates
AC 22/16 base main driving lanes on concrete tiles & foundation layer. AC 16 base bike paths	asphalt (STAB) partial recycling 20 %

Some remarks on the products in the table. The two products "AC bin base 50%PR cat. 2" and "AC surf 0%PR cat. 2" together contributed 74% of the MKI of the project. These two products are used for the materials bus stop asphalt, bike path asphalt red, roadway asphalt, milling and removal of asphalt cycle path, and the milling and removal of asphalt 8 and 21 centimeters. The two products are branch representatives, which means sector averages. Five products use these two DuboCalc products while not being the same products.

One projects uses much concrete. All concrete products are entered in DuboCalc as "C20/25" or "C30/37". This means no specific way of processing is included in the MKI score for any of the products. The concrete is used in many different ways, making it unbelievable all concrete fits the description. The same counts for rebar. This product is also used in many different products and is always assumed to be 150 kg/m³, even for implementation in other products. An assumption is that the NMD only contained a rebar with 150 kg/m³ at that time, so that assumption has been made to ease the calculation.

Something that happens a lot is that the design phase delivers other products than DuboCalc contains. Then, the products are mentioned in the design, and the MKI executor fitted a product to it. That product may be made from that material, but this happens so often, which begs the question if it is all accurate. The NMD has many materials in the database, but the same qproducts are used most of the time.

4.3. Literature review

4.3.1. Underrepresented circular construction products in the GWW sector

Materials required for MKI calculations of projects are not represented enough, especially not the circular and sustainable building materials that will be used in the future. The appendix Circular construction products in the GWW sector state which materials are the materials of the future in civil engineering. According to PIANOo (sd), these are products that are important for sustainable construction in the GWW sector, which are currently not represented in the NMD:

- Biobased street furniture
- Biobased bank protection additives in asphalt and concrete
- Old asphalt. Sustainability depends on which materials are used and if they are recycled already. Rijksoverheid (sd) distinguishes between recycled and new materials in their awarding criteria.
- Dismountable construction. Parts or products that can be dismantled at the end of their lifespan and elements of which the lifespan is not over can be used in other projects.
- 3-d printing with different materials, according to Wolfs (2019).
- Environmental profiles for wooden structures, according to Ministerie van Infrastructuur en Waterstaat, (2022).

The government has a list of requirements and award criteria for projects in the GWW sector. These are award criteria for the subjects: civil constructions, conservation works, cables and pipes, groundworks (site preparation), sewerage, street furniture and playground equipment, traffic management installations, water treatment plants, sludge treatment, and roads (Rijksoverheid, sd). These products are essential for the tenders of projects in the GWW sector that are not (good enough) represented in the NMD:

- Sustainable steel design constructions
- Reinforcement in concrete
- Industrial concrete plates
- Set concrete
- Ecotoxicity chemicals
- Phosphate recovery from cables and pipes
- Reusing released soil
- Energy-efficient light sources
- Road infrastructure as an energy source
- Circular materials
- Recycled plastic

4.3.2. Category one data

An extensive testing protocol must be followed when a company wants a product to be included in the NMD. Due to all these steps and requirements, this process takes a while and costs money. This prevents companies from including their products in the NMD. Currently (17-06-2022), the NMD contains 745 elements in the GWW sector, of which 46 are from category one, which are products that companies have added to the NMD.

Besides the effort, including a product in the NMD costs money. The fixed charges of two product cards are 479,- annually for companies, and 761,- for branches with three product cards (Nationale Milieudatabase, 2022). When a data supplier wants more than two product cards to be included in the NMD, this costs 68,- for the first 13 cards for companies and 149,- for the first 12 cards for branches.

Another reason why there is not much category one data available is due to company-sensitive information. Parts of the MKI calculations are often not made in DuboCalc by contractors. Outsourcers have project-related LCAs made in programs other than DuboCalc, and the data is not included in the database (Oostdijk, Dreef, & Schellekens, 2019). This is allowed as long as it is done by the rules of the "Bepalingsmethode" (PlatformWOW, 2021), which is "a uniform measuring method to calculate the environmental performance of construction works unambiguously, verifiably and reproducibly" (Stichting Nationale Milieudatabase, 2022). An example of this is the Excel file Witteveen + Bos uses instead of DuboCalc when DuboCalc is not required. This is why detailed information on products from category one is often missing.

4.4. Conclusion

Several individual products and materials that are not well represented in the NMD are identified. The type of missing materials depends on the projects that were researched. So far, no unambiguous conclusion can be drawn about which materials are precisely missing. Most products are from category three and managed and included in the database by the NMD. This is in accordance with what Ronald Hendriks says in the interview, "as soon as you need products that are not needed for Rijkswaterstaat projects, there is not much available, materials that are not often used in civil engineering are poorly represented." To conclude, specific materials not used often in the GWW sector or by Rijkswaterstaat are missing from the NMD.

The literature has shown that many materials and products that are (or will be) used in the circular construction industry are not yet available in the NMD. This mainly concerns biobased and recycled materials, and is essential for encouraging sustainable engineering. Not many companies products are included since quite some effort and money goes into getting a product LCA approved. Besides, for many projects, it is not necessary to use DuboCalc, which means it is not necessary to include the data required.

5. Standardized method for missing materials

This chapter will explain the different methods of dealing with missing products and how those methods are composed. The previous chapter mentioned the causes, this chapter will explain methods to deal with the challenges. First, the problems solution will be analyzed through interviews and literature review. Then, the standardized method is presented with an explanation of the used methods to answer the question: what is a standardized way of solving the missing product's problem?

5.1. Interviews

According to the interviewees, there are two main ways of finding a solution when a product is missing. The first option is looking for the best alternative in the NMD. In the exploration phase of the project, this is favorable since the MKI does not have to be very accurate but merely has to be an indication. The second option is calculating the LCA score with SimaPro, a program specialized in LCA calculations.

5.2. Literature review

5.2.1. Calculating the LCA another way

With the importance of building sustainable, many companies are specialized in and offer services in calculating LCA scores. This is done in multiple ways, companies offer the service of calculating the LCA value or supply the software to let the user calculate the LCA.

Calculating LCA

The most inclusive and controllable way is to use SimaPro. This program has "the solution to collect, analyze and monitor the sustainability performance data of products and services" (SimaPro, 2022). With SimaPro, the user has to set up the whole life cycle analysis of a product from cradle to cradle by hand. Another program is One Click LCA, which is "the #1 easy and automated life cycle assessment software that helps you calculate and reduce the environmental impacts of your building & infra projects, products, and portfolio" (One Click LCA, sd). This is a web-based program with over 126.000 data points in the construction industry for compliance tools, early design optimization, Life Cycle Costing, circularity assessment, and infrastructure LCA.

Outsourcing LCA calculations

Besides offering software, some companies calculate the LCA themselves. Examples of such companies are Enperas, TAUW, and SGS Search, which are quite similar. Enperas, for example, is a company that does LCA consultancy and creates LCA backgrounds including EPD. These companies are specialized in executing LCAs. The LCA and EPDs they offer adhere to the European standard for LCAs in the construction sector, the EN15804, and can be used in MKI calculations.

5.2.2. Similar methods and databases

Gideon is a company that focuses on getting the construction industry to move and change in a sustainable direction (Gideon, sd). They executed an exploratory research and wrote an advice to the minister on how to improve the MKI system in its entirety. Five highest priority points of attention have been set up. Two of which are: to improve the database accessibility for new products and to upgrade data quality (Bosch, Anink, & van Leeuwen, 2022). There are a lot of other databases that also conform to the EN15804, which have different data included than the NMD. Integrating these databases could improve the amount and quality of data used in the MKI determination process. Besides countries, some organizations keep and manage environmental databases. All these databases contain EPDs, just like the NMD. The data format is essentially the same, containing data useful for projects in the Netherlands. The databases are stated in Table 6.

Table 6: other databases

Database	Source	Free to use	Number of datasets (5-6-2022)	Conforms to	Contents
Nationale Milieu Database	(Nationale Milieudatabase, 2022)	yes	2.904	EN15804	soil, road, and water construction sector construction and utility sector
Ecoinvent	(Ecoinvent, 2022)	no (free via SimaPro)	> 18.000	EN15804	diverse range of sectors on global and regional level
Eco-platform	(ECO Platform, 2022)	yes	3.583	EN15804	building and construction
CPM LCA	(Swedish Life Cycle Centre, sd)	yes	748	ISO 14042 & ISO 14048	product and material systems
INIES	(INIES, 2020)	yes	2.987	EN15804	reference environmental and health database for building sector containing construction products, equipment, and services.
Ökobaudat	(Bundesministerium für Wohnen, Stadtentwicklung und Bauwesen, 2021)	yes	> 1.400	EN15804 & ISO 14042	life cycle assessment datasets on building materials, construction, transport, energy and disposal processes
ProBas	(Umwelt Bundesamt, 2015)	yes	> 8.000	ISO 14040 & ISO 14048	Energy, materials and products, and transport

5.3. Standardized method of dealing with missing products

This section will explain the standardized method of dealing with missing products. Table 7 shows the results.

Table 7: standardized method of missing materials

Method	Required knowledge	Time required	Accuracy MKI	Effort	Additional remarks
1. Use an alternative product in DuboCalc	EPD of the product with basic specifications	low	low-middle	low	MKI accuracy is highly case-specific
2. Calculate the LCA	much information about the life cycle required	middle-high	high	middle-high	license required, time consuming when new to the program
3. Estimation based on other data sources	EPD of the product with basic specifications	low-medium	middle	middle	can be time consuming without result
4. Outsource the LCA	low	high	high	low	pricing

Many factors influence which method to use. There is no right or wrong method. The table shows method specifications which help choose the method. It is up to the MKI executor to decide which method to use based on the situation. When data is required that is not available, the appendix Data gathering tips can be consulted. The following chapters explain the results, which are four methods of dealing with missing products in the MKI determination.

5.3.1. Use an alternative product in DuboCalc

The simplest option is to use an alternative product in the NMD. This method is derived from the interviews. It is mentioned as the main method of dealing with the problem. It is up to the MKI executor to find the best fitting alternative for a product. Points of attention to keep in mind when using this method:

- Density of the materials. The density of the product says a lot about the contents. Most of the time, not much product information is available, but density often is or can be found with some research.
- Phases of the life cycle of the product. A product that fits the role of another product well should have equal processes in the life cycle. This indicates that production, construction, use, demolition and processing, and end-of-life phase are in accordance.
 - Consider the impact of the phases, low MKI impact means less importance.
- Functional Unit. The product might have to be rescaled to fit the size of the other product, which means it is useful that the functional units are the same. When functional units are the same, this is easy, but additional information is required for converting when they are not the same.
- Same country or region of origin of the product. When the products have the same origin, the chance is more significant that they are more alike. It also means transport distances are more likely to correspond.

5.3.2. Calculate the LCA

The second alternative method is to calculate the LCA yourself. Depending on the experience of the MKI executor with executing LCA, a choice can be made which program to use. The first method is based on the results of the interviews, the second method is based on desk research.

SymaPro

The first and most inclusive way is SimaPro, of which Witteveen + Bos owns the license. The advantage of this program is the inclusiveness of the LCA. The whole life cycle is set up by hand, and every part is adjustable and specific for the product. The disadvantage is that it takes a lot of time to make the LCA of a product. Especially inexperienced people who work with the program will take a lot of time to get an accurate MKI value. SimaPro includes the Ecoinvent database, which contains reliable environmental data.

One Click LCA

The second option is a web-based app called One Click LCA. According to reviews, the software is an excellent guideline for identifying the carbon-intensive areas of the design and material choice (4,6 out of 5) according to eighteen reviews (Capterra, sd). The program conforms to the EN15804 and displays the information as an EPD. According to reviews, the software is easy to use, but a disadvantage is that the software license is expensive, and the online training on the programs also has to be paid for.

These two programs work a bit different. For SimaPro, more effort is required, but it probably leads to a more inclusive LCA score. One Click LCA is easier to use and faster. Both programs results can be used in the same phases of MKI calculations.

5.3.3. Make an estimation based on another data source

This method is based on literature review but still needs a lot of additional research and elaboration. Other EPD data can be used when the MKI calculation does not have to be done in DuboCalc. Then, other databases which are mentioned earlier can be used. "Even though harmonization (of environmental databases) is difficult, it is not impossible. There are many occasions where harmonization was successful, like ISO standards, national databases, initiatives taken by groups of stakeholders, and many more" (Putnaergle, 2020). Table 6 is an overview of the databases and some specifications which can help determine if the database may contain the searched product. When these databases do not offer a solution, research can be done with alternative sources. The legitimacy of the data should be kept in mind. This can easily be checked by looking if the data source complies with the EN15804 or other European standards on LCA or EPD assessment like the ISO 14048.

5.3.4. Outsource the LCA

This method is based on desk research. Outsourcing the LCA to companies specialized in LCA calculations may be useful in some cases. Many specialized organizations exist who offer this service. There are advantages and disadvantages to this method, first the advantages:

- The LCA calculation is accurate.
- The product can probably be included in the NMD effortlessly since an expert executed the LCA. Another certified expert still has to check it, but this will not cause problems since an expert has already made the LCA.
- Outsourcing the calculation saves time and effort.
- The detailed LCA analysis of the product can be used in the future for similar products or to analyze the LCA.

On the other hand, there are disadvantages:

- Outsourcing the LCA costs money. It depends on the extensiveness of the LCA and what the costs are.
- Communication of the specifications of the product. The party who executes the LCA does not know as much about the product as the party requesting the LCA. Information like the origin of the product's materials, for example, is probably not known by the LCA executor and must be communicated.

Things to take into consideration when determining if the LCA is possible to outsource:

- The estimated MKI impact of the product.
- How many times will the LCA or MKI be used?
- The desired accuracy of the product's MKI.
- The timespan in which the LCA is needed.

When outsourcing the product. A document stating the exact assignment should be drawn up and sent to companies that do that service. A recommendation is one of the following three companies:

- Enperas: <https://www.enperas.com/en/>
- TAUW: <https://www.tauw.nl/op-welk-gebied/circulaire-economie/levenscyclusanalyse.html>
- SGS SEARCH: https://www.sgssearch.nl/?gclid=CjwKCAjwqauVBhBGEiwAXOepkfH3VzKnx4-bXPfjT5lIdowcvDGbMU_sa_NTId0-Gd6Nz3NfS5dJ_BoCL_AQAvD_BwE

5.4. Conclusion

Products not being available in the NMD can cause inaccuracy in the MKI and time loss. The interviews and multiple reports confirm the problem. For this problem, four methods are developed for what to do in case a product is unavailable in DuboCalc. Many factors influence which method to use, there is no right or wrong method. It is up to the MKI executor to decide which method to use based on the situation. The methods are using an alternative product in DuboCalc, calculating the LCA, making an estimation based on another data source, and outsourcing the LCA.

6. Discussion

Points of discussion about this research are discussed in this chapter. First, the interviews will be discussed, then the methods, and at last the guideline.

6.1. The interviews

The research started off with interviewing users of the program, which led to a lot of useful information. It was concluded that the sub-question 1 and 3 should be adjusted since they did not fit the purpose of the research. In total, five interviews were held. In hind sight, two of those interviews should have been held during the proposal writing phase of the project for a more efficient start. For a more conclusive image of the MKI determination system, experts and people who manage/develop the NMD and DuboCalc should have been interviewed. This are employees from companies like Stichting Nationale Milieudatabase, Cenesco, RoyalhaskoningDHV, or Rijkswaterstaat. Another interview that would have been interesting is with an LCA expert. Three LCA experts were contacted via email, only one responded succinctly, which is not inviting for an interview.

6.2. The methods

Of the seven methods developed in this research, three are invented by the author. One method is based on desk research (outsourcing the LCA), one on the failure of the current method (element or phase scaling), and one on literature and desk research (estimation based on another database). These methods are not good (enough) scientifically substantiated. Due to time constraints, little research could be done on why some phases and elements do not scale proportionately, which is important in understanding the problem and developing a solution. When this is researched more extensively, a good conclusion about the best research method could be given. It is assumed that the method "Schalingsformules" from Rijkswaterstaat is best, but this is not researched. This is the same for the missing product problem. An example of this are the cases studied. The conducted case studies were all in the road sector of the GWW sector. These were available and had enough information to be analyzed. With more time available, more cases from all parts of the GWW sector could be researched. The methods are drafted as feasible methods with more research necessary, but no time was available to research them extensively or test them. This counts especially for outsourcing the LCA and estimation based on other databases, since they are not mentioned by the interviewees. Due to time constraints, the developed methods are not verified and validated which has to be done before using these methods. Because of this, no best or worst method from the missing product problem can be concluded.

6.3. The guideline

The goal of this research is to improve the accuracy and efficiency of DuboCalc. Neither have been tested. Due to time constraints, the guideline developed in this research is not tested. The guideline is understandable for the developer, but it is not tested on others. It would be good to receive feedback by users of the program on the usability of the standardized methods. These users of DuboCalc all work in the group CO₂ focused and circular design or circular and biobased solutions. There is little time available to become an expert and teach or advise people whose work is circular designing or circular biobased solutions. For that reason, the feedback on the guideline of the interviewees could be have been very useful and be processed and integrated into the guideline. The feedback could also determine if the efficiency has been improved. The guideline has also not been validated or verified, which must be done before using it.

7. Conclusion

The goal of this research is to design an additional guideline that improves the accuracy and efficiency of DuboCalc, and has led to a guideline called: "A guideline for scaling and missing products in DuboCalc" (Staarman, 2022). This chapter will summarize the findings of the research. The four sub-questions will be answered to answer the main research question.

7.1. What are the causes of the scaling product problem?

The general solution of the interviews is that the problem of scaling products is caused by missing information and a missing standardized scaling method. The general tenor is that products with functional units m, m², or piece cause problems because they can scale in different dimensions than their functional unit. Products with functional units kg, m³, hour, km, kWh and tkm are not causing problems when scaling. The cause of the problem when scaling products is the lack of information available on products. Little information available makes it hard for the MKI executor to determine how the product should be scaled.

7.2. What is a standardized method of solving the scaling product problem?

Five examples of products are researched to prove that some parts of products, phases, or elements do not scale proportionately with regard to the 'main' product. To reduce the margins of errors when scaling products, two methods have been developed. These methods are not always applicable, which is why a third method is presented which can always be used. These methods are integrated into a flowchart to form a standardized method. The flowchart helps the MKI executor decide which of the three scaling methods to use. The first choice is to determine which phase the project is in, which determines the required MKI accuracy. Then, the flowchart can be followed, which can be found in the deliverable. The three methods of scaling hierarchized to improve the MKI accuracy are:

1. Scaling formulas
2. Element scaling or phase scaling
3. 1,2 or 3-dimensional scaling

The MKI executor still has to do the work and think about how to address the problem. To help the guideline users, additional help is presented for the choices in the flowchart.

7.3. What are the causes of the missing product problem?

The type of missing materials depends on the project. So far, no unambiguous conclusion can be drawn about which materials are precisely missing. Most products are from category three and managed by the NMD, so almost all products are entered by the Stichting Nationale Milieudatabase. This is in accordance with what Ronald Hendriks says in the interview, "as soon as you need products that are not needed for Rijkswaterstaat projects, there is not much available, materials that are not often used in civil engineering are poorly represented." To conclude, specific materials not used often in the GWW sector or by Rijkswaterstaat are missing from the NMD.

The literature has shown that many materials and products that are (or will be) used in the circular construction industry are not yet available in the NMD. This mainly concerns biobased and recycled materials and is important for encouraging sustainable engineering. Not many companies products are included since quite some effort and money goes into getting a product LCA approved.

7.4. What is a standardized method of solving the missing product problem?

Products not being available in the NMD can cause inaccuracy in the MKI and time loss in the process, which is why it must be solved. With this amount of time and resources available for the research, no standardized method is found for solving the problem of missing materials. The findings of this research are all ways to work around the problem of the lack of products in the NMD. There is no standardized way (yet) to deal with the missing products because many factors make each problem unique. The methods are not long-term solutions for the problem. A recommendation is to integrate the data from the European databases conforming to the EN15804. Four methods of solving the problem are found, in a random order:

1. Search for an alternative product
2. Calculate the LCA with a program
3. Make an estimation based on another data source
4. Outsource the LCA

7.5. How can a guideline be designed which goal is improving the accuracy and efficiency of DuboCalc?

To improve the accuracy and efficiency, a guideline is designed which helps the user choose which methods to use for scaling and missing products. No unambiguous method for the problem of scaling products was found. A flowchart has been created for scaling products with three methods. The flowchart contains four choices the MKI executor must make to decide which method to use. No unambiguous method is found for the missing products either. The solution is highly dependable on the situation and is, therefore, too complex to design in a standardized way. A table with the four methods and the advantages and disadvantages have been created for the MKI executor to help choose which method to use. The resulting methods have been explained in detail to the user for both standardization attempts. The main causes of both challenges are the lack of availability of products and information on product cards.

The deliverable has not been validated or verified. Due to time constraints, not all methods could be researched and developed as preferred. This standardization attempt is a start and needs follow-up research. Table 8 is an overview of the methods for both challenges. It states why and how the methods are developed, the MKI accuracy, advantages, disadvantages, and research recommendations.

Table 8: overview of the methods

	creator method	substantiation	valid- ated?	MKI accuracy	disadvantage	advantages	recommendations on further research of method
scaling formulas	Stichting Nationale Milieudatabase	"De toepassing van de Schalingsformules in de NMD 3.0"	yes	medium-high	lot of information required	good accuracy	integrate element and/or phase scaling to this method once researched sufficiently
element or phase scaling	author	- expert opinion - logical reasoning - researching NMD products	no	medium-high	-not scientifically substantiated -not available for FU: kg, kWh, tkm, hour, km, m ³ -lot of information required	better accuracy then 1,2,3-dimensional scaling	-proof phases and elements do not scale proportionately - research how phase and elements scale with regard to sizes
1-dimensional scaling	Stichting Nationale Milieudatabase	"Bepalingsmethode Milieuprestatie Bouwwerken"	yes	low-medium	-	-simple, fast method -not much information required	as explained in this report, scaling happens often not proportionately which this method assumes, general research about scaling is required
2,3-dimensional scaling	Stichting Nationale Milieudatabase	-logical reasoning -"Bepalingsmethode Milieuprestatie Bouwwerken"	no	low-medium	-	-simple, fast method -not much information required	- literature research backing up this method (or not)
SimaPro	interview users	- certified method, ISO 14067 & ISO 14040 compliant	yes, EN15804	high	-lot of effort	MKI calculation complete in own hand	-
One Click Lca	author	- reviews - certified method	yes, EN15804	medium-high	-costly	little effort	validate the MKI results
using an alternative product	interview users	- logical reasoning - literature research	no	low	- highly case dependent if the method is successful	-little effort	literature research on which products can be easily substituted and which phases to account for
estimation based on other data sources	author	-logical reasoning -certified methods	yes, EN15804	medium	-cannot be used in DuboCalc - lot of effort	- a lot of data in other databases.	develop a harmonized environmental database
outsource the LCA calculation	author	logical reasoning	yes, EN15804	high	- costly	- little effort	research the best companies

8. Recommendations

This research has most of all been exploratory research. The flaws and challenges of the general MKI system have been researched. This research has much follow-up research potential since the area of expertise is broad and sustainable developments in the civil engineering sector continues. This chapter presents research recommendations for improving the MKI determination system.

8.1. Researching additional literature

Due to time constraints, some literature would have been good for the inclusiveness of the project. Missing literature contains a list of topics that have been researched but no information on it could be found or could not be researched due to time constraints. The most important literature to research additionally is inaccuracies in current MKIs, improving the data availability and quality in the NMD, and researching scaling methods.

8.2. Harmonizing environmental databases

Due to the European standard EN15804, there is a lot of data on environmental impacts in the construction industry with the same data format free available. Even though the data conforms to the same rules, this data cannot be used due to regulations. This is a shame because much positive would be gained if these databases and methods could be harmonized to form one uniform method and data source. All European countries would benefit from one extensive harmonized database. One of the biggest problems in the Dutch MKI system is the lack of available data and products. "Even though harmonization (of environmental databases) is difficult, it is not impossible. There are many occasions where harmonization was successful, like ISO standards, national databases, initiatives taken by groups of stakeholders, and many more" (Putnaergle, 2020).

8.3. Research the element and scaling method

This research aims to improve the accuracy and efficiency of DuboCalc, which suggests that it is currently inaccurate. This hypotheses is not proven. Not many sources are found of MKIs that have proven to be inaccurate. The element or phase scaling method is based on the fact that some phases of products in the NMD did not scale proportionately when analyzing different sizes. As also stated in the literature that still has to be researched, the methods that counter that scaling problem are not backed up scientifically. They merely calculate a better estimation of the MKI based on the information available, and reduce the margin of error. No research was done to validate or verify the two methods, which is recommended before using them.

8.4. More inclusive case studies

The conducted case studies are all in the road sector of the GWW sector. The case studies would have had better conclusive results if all parts of the GWW sector were studied, which is recommended in future research.

8.5. Environmental impact determination of Module D

In 2015, a proposal for improvements in the implementation of Module D (recycling and reusing building materials) in the "Bepalingsmethode" to make it further suitable for recycling and reuse was published. This report has the goal to formulate a proposal for an upgraded implementation of Module D from the EN15804 in the "Bepalingsmethode" (Levels-Vermeer, van Ewijk, Scheepmaker, & de Vries, 2015). This research concluded that the differences in environmental impact over the entire life cycle with regard to the reference situation caused by allocation differences are a maximum of 50%. This means that through different choices within the LCA method, the environmental impacts of products in module D can differ up to 50% due to allocation differences. This has to

do with the different interpretations module D can have. The differences come from “the application of the end of waste criterium for allocation, interpretation of avoided products and free interpretation of system boundaries at waste incineration and waste scenarios” (Levels-Vermeer, van Ewijk, Scheepmaker, & de Vries, 2015). A maximum difference of 50% in MKI is much for a program designed to calculate MKIs accurately. The current method should be revisited to reduce this number.

8.6. Improving data quality

A way of improving the data availability in the NMD is obliging a standard amount of information when including a product in the NMD. This can be a specification list, the heritage of the data (if category three), the way it scales (proportionately or not), or a picture for example. It is not a lot of trouble for the MKI executor or product owner to include some information. This can save DuboCalc users lots of time researching products.

8.7. A shared additional DuboCalc file/program

For the integration of knowledge, a DuboCalc user platform would help. This is where users can store and share information and solutions to deal with challenges. When a product with many components is created, this can be put in a forum and used by other DuboCalc users. For example, the platform can contain elaborations and additional information on products and how they scale. Users of DuboCalc will be encouraged to import their findings into the database. The intrinsic motivation will be that they also use DuboCalc and benefit from much helpful information stored in the database. Over time, the database will be filled with information. Eventually, this should help the efficiency of MKI determinations.

8.8. Control and testing protocol

An interviewee stated that there is a need for a testing protocol at the end of the MKI calculation. A uniform document that helps verify that the MKI has been executed properly and nothing has been overlooked. This would ease the process and ensure the MKI has been calculated inclusively. Additionally, it helps in making the whole MKI determination method more standardized.

8.9. Performance web app

The DuboCalc 6.0 web app does not work properly due to lagging and bugging, which is why Witteveen + Bos uses an Excel file when DuboCalc is not required. The main hindrance when using the web app is that it is slow. This can probably be fixed by downloading the database instead of having to use an online version.

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10.2. Glossary

- **Bepalingsmethode** “A uniform measuring method to calculate the environmental performance of construction works unambiguously, verifiably and reproducibly” (Stichting Nationale Milieudatabase, 2022) .
- **DuboCalc** Duurzaam Bouwen Calculator
- **Ecoinvent** “Publisher of the world’s most consistent & transparent life cycle inventory database” (Ecoinvent, sd).
- **EPD** Environmental Product Declaration, a summary of an LCA, and information available on the product cards in the NMD.
- **EN15804** “Provides core product category rules (PCR) for environmental declarations for any construction product and service” (NEN, sd).
- **GWW sector** Soil, water and road construction sector
- **LCA** Life Cycle Analysis, a method to calculate the total environmental impact of a product or process from cradle to grave.
- **MKI** Milieu Kosten Indicator (environmental impact indicator) is the environmental impact of a product or project summarized in one score in euros.
- **NMD** Nationale Milieudatabase (national environmental database)
- **Tender** A process where an instancy/client invites bids for a (large) project.

10.3. Interviewing experts

Naam:

- 1: *Cis Huinink*
- 2: *Ronald Hendriks*
- 3: *Dieuwertje Roelofsen*
- 4: *Wouter ter Heijden*
- 5: *Bas Roelofs*

Wat doe je binnen Witteveen + Bos:

- 1: *Project ingenieur voor circulaire economie*
- 2: *LCA specialist in de groep CO₂ gestuurd ontwerp*
- 3: *Ik doe onderzoek naar duurzame drinkwaterketens en circulaire waterketens, ik werk inmiddels bijna 3 jaar bij Witteveen + Bos.*
- 4: *Ik ben adviseur circulair ontwerpen voornamelijk in de gebouwde omgeving.*
- 5: *Ik ben adviseur circulaire oplossingen voor zo'n 1,5 jaar. Ik houd me vooral bezig met MKI berekeningen, LCA studies en circulariteit studies.*

Hoeveel ervaring heb je met DuboCalc:

- 1: *7 maanden..*
 - 2: *1.5 jaar, ik ben degene met de meeste ervaring met DuboCalc binnen Witteveen + Bos.*
 - 3: *1 jaar.*
 - 4: *Divers, begin van projecten tot toepassen voor berekeningen en indicaties tot aanbesteding.*
- Divers, ik gebruik het bij begin van projecten, in de verkenningsfase. Ook voor het toepassen voor berekeningen en voor indicaties tot aanbesteding.*
- 5: *Ik gebruik het meestal in de ontwerpfase van een project om MKI berekeningen mee te maken. Het begint met het schetsontwerp, dan naar het voorontwerp en uiteindelijk het definitieve ontwerp. Tijdens de evolutie van het ontwerpproces zie je dat de MKI berekeningen preciezer wordt. Er is meer data beschikbaar naarmate het proces vordert. Daarnaast gebruik ik het ook om LCA berekeningen voor tenders om te rekenen naar een MKI.*

Welk soort projecten werk je vooral aan binnen de GWW sector?

- 1: *Ik werk om het ontwerpteam advies te geven over circulaire en duurzame oplossingen. We gebruiken DuboCalc vooral omdat het wordt gevraagd vanuit de opdrachtgever, het is namelijk redelijk laagdrempelig. Ik gebruik DuboCalc voornamelijk om de circulariteit van projecten proberen te verbeteren, ervoor zorgen dat er lagere MKI waardes worden behaald.*

2: Ik ben de DuboCalc expert binnen Witteveen + Bos. Ik controleer voornamelijk het werk van andere DuboCalc gebruikers. Dat gaat dan om het modeleren van projecten voor opdrachtgevers. DuboCalc gebruiken we ook andersom, als tenders voor aannemers. Daarnaast ben ik bezig met DuboCalc te verbeteren.

3: -

4: Ik houdt me voornamelijk bezig met dijken, wegen en sluizen.

5: Vrij divers, ik gebruik DuboCalc voornamelijk voor rioolwater zuivering, wegenbouw en dijken.

Herken je het probleem van het schalen van producten in DuboCalc en hoe ga je momenteel met deze problemen om?

1: Ja. Over het algemeen rekenen we de producten om naar een makkelijke eenheid om mee te rekenen en te schalen, meestal is dat gewicht. Dan vermenigvuldigen we het naar de benodigde hoeveelheid en dan wordt die berekening dan gemaakt. Het probleem met deze methode is dat de foutmarges hierdoor steeds groter worden.

2: We zoeken naar een factor die het meest passend is om te schalen bij een product. Welke het meest logisch is wordt gebruikt om te schalen en meestal is dat massa.

3: ja.

4: Ja. De schaling maak je zelf in Excel en dat kost tijd. Het product is vaak niet representatief voor wat het wel moet zijn, zo moet je over elk product nadenken wat ermee moet gebeuren. Je moet goed opletten welke onderdelen je kan verschalen, of de processen bijvoorbeeld niet veranderen maar de materialen wel. Het gebruik hiervan is niet handig tijdens de aanbestedingsfase.

5: Ja. In zeldzame gevallen is schalen mogelijk maar bijna altijd moet je gaan omrekenen. Het probleem is dat je dan alle dimensies mee schaaft. Het is te complex om dit op te splitsen en de informatie is niet beschikbaar om dit goed te doen. Als je iets schaaft worden alle fases mee geschaft. Dit doe je liever niet maar moet vaak wel en dit brengt foutmarges met zich mee. Als dit gebeurt wordt het wel in de opmerkingen meegenomen. Iemand anders controleert dat dan na afloop en alle onnauwkeurigheden worden gedocumenteerd en beoordeeld.

Bij welke soort producten ervaar je deze problemen?

1: Balken, buizen, geo-textiel, en damwanden. Het gaat vooral over producten met specifieke specificaties. Producten die duidelijk voor 1 doel in de NMD staan.

2: -

3: -

4: Voornamelijk bij lichtmasten, hier ontstaan problemen tussen de aanbestedingsfase en het controleren hiervan.

5: -

Hangt het ook af van de Functionele Eenheid dat producten lastig te schalen zijn, kg, stuks of m²?

1: Ja. Producten met de eenheid strekkende meter zijn vaak lastig waardoor de foutmarge vrij groot is en de onzekerheid toeneemt. Daarnaast is de FE stuks ook lastig en de FE kilo's is makkelijk.

2: Ja. Producten met de eenheid massa of volume zijn makkelijk te schalen. Producten met de FE m² zijn lastiger te schalen, dat is waar de problemen liggen. Eenheden die 1 dimensie vaststellen zijn ook lastig, de rest schaaft dan mee maar dat wil je niet.

3: Voor mijn werk specifiek is strekkende meter lastig, dan moet je op basis van de informatie in het bijschrijft het product schalen.

4: Er is altijd wel achterliggende data bij categorie 3 te vinden waarmee je er wel omheen kan werken. Je kan in principe er altijd wel omheen rekenen.

5: De eenheden kuub en massa zijn makkelijk. Funderingspalen worden lastiger doordat de functies ervan kunnen verschillen. Informatie mist om het goed om te schalen. Daarnaast kan informatie uit verschillende ontwerp fases verschillen en dat kan ook lastig zijn. Leidingen en funderingspalen zijn in meters wat meestal niet handig is.

Herken je het probleem dat er materialen ontbreken in de NMD en hoe los je ze op?

1: Ja. Dit is het grootste probleem, dat producten niet beschikbaar zijn. Er zijn 2 opties hoe je hiermee omgaat.

De eerste optie is het zoeken van een vergelijkbaar product: een zo goed mogelijk aansluitend product dat als vervanging kan dienen. Dan kijken we naar de milieu impact scores en achterliggende documenten om zo een goede keuze te maken voor welke producten vervanging mogelijk is. Dan kan je ook denken aan vergelijkbare soorten producten en dan omrekenen en schalen.

De tweede optie is dat het product er helemaal niet in zit. Dan moet je een zo goed mogelijke benadering zoeken. Er zijn 2 manieren om dit op te lossen. Óf een beste schatting maken óf buiten DuboCalc om LCA bereken software gebruiken om zo erachter te komen wat de waardes zijn. SimaPro is zo'n soort LCA programma om LCA's van specifieke producten te berekenen. Het nadeel is wel dat het een lastig en tijdrovend programma om te gebruiken is.

2: Ja. Er zijn 2 routes hoe je dit kan oplossen.

Óf je vind het dichtstbijzijnde item binnen DuboCalc. Het ligt eraan hoe gedetailleerd de berekeningen moeten zijn of dat wel of niet kan. Als het niet heel accuraat hoeft te zijn kan je makkelijk een vervangend product kiezen. Dit gebruiken als je in het vroege stadium van het project zit, als bijvoorbeeld de specificaties van het product nog onbekend zijn.

De andere optie is zelf binnen SymaPro het product modeleren of bij leveranciers data aanvragen. Je kan op deze manier zelf betere data aan DuBoCalc toevoegen die je vervolgens kan gebruiken als oplossing voor het missende product.

Witteveen + Bos gebruikt een eigen Excel in plaats van DuBoCalc voor veel projecten. Dit kan zolang het maar voldoet aan de "Bepalingsmethode". Zijn vaak wel problemen met data overzetten en invoeren in DuboCalc, dat gaat lastig.

3: Ja. Niet, je zoekt ze op in de NMD viewer of je gebruikt LCA software zoals SymaPro.

4: Herkenbaar, bij DuboCalc kan je geleend items van de B&U gebruiken voor de GWW. Je gaat altijd opzoek naar het meest representatieve item en je moet eerlijk zijn als het niet helemaal accuraat is en dat documenteren voor de DuboCalc beoordelaars. Die kunnen dit product dan extra nakijken.

5: Wijk je af van de classic GWW studies en dan komen de problemen bovendrijven. Dit is voornamelijk bij complexere objecten met specifieke benodigde producten die niet vaak in de GWW worden gebruikt. Voor mijn gevoel is DuboCalc meer op de infra kant van de GWW gericht en dijkenbouw. Er zijn 2 opties hoe je met deze problemen omgaat. De eerste is een ander onderdeel schalen en dus opzoek naar een vergelijkbaar alternatief. Het tweede is vanuit LCA data een MKI opstellen maar dit mag alleen in ontwerp studies en is niet toegestaan voor tenders in de aanbestedingsfase.

Bij welke soort producten is dit probleem het vaakst?

1: Hout, stalen damwanden (1 beschikbaar), roestvrij stalen producten (2 beschikbaar) en grondsoorten. Dit zijn grondsoorten zoals zand, klei en aarde. De MKI waarden van deze grondstoffen kunnen veel verschillen op basis van een klein verschil. Je weet niet goed welke je dan moet kiezen want de achtergrond info is niet beschikbaar of niet compleet.

2: Hier wordt op dit moment onderzoek naar gedaan. Zodra je producten nodig hebt die niet voor Rijkswaterstaat projecten zijn is er vaak veel niet. Materialen die niet veel in de GWW worden toegepast bijvoorbeeld zijn slecht gerepresenteerd.

Composities van materialen zijn lastig net als nieuwe producten zoals geo-polimeren en polimeren. Daarnaast zijn er weinig koper elementen aanwezig. Bij elektriciteit een beetje en een beetje bij leidingen.

Welke materialen ik het liefst LCA approved zou krijgen zijn damwanden in verschillende groottes, en stalen balken. Daarnaast een aantal houtsoorten en duidelijk gedocumenteerd wat de verschillen tussen de houtsoorten en de houten balk zijn voor het kiezen.

Ook is er naar één waarde voor betonwapening. De wapening kies je los van het beton maar soorten beton hebben een ander percentage wapening erin. De vraag is dan hoeveel wapening je in het beton wilt hebben.

Stalen objecten zijn ook niet optimaal, een afweging kunnen maken tussen recycled of nieuw staal zou handig zijn.

3: Dit probleem is het vaakst bij basis producten zoals staal en aluminium. Deze materialen zijn niet los beschikbaar maar alleen maar als materiaal in een product. Specifieke producten wel maar algemene zijn vaak niet beschikbaar. Het alternatief is dat dat je al gauw naar de LCA database in SymaPro gaat, die is van Ecoinvent.

4: Bij het gebruik van DuboCalc voor de aanbesteding is het vaak een inschattingen. Categorie 3 data wordt hier vaak gebruikt want daarvoor zijn vaak veel generieke producten nodig. Over het algemeen staan de producten die veel bijdragen aan de MKI er vaak wel in.

Specifieke dingen staan er vaker niet in, met minder MKI impact. Voor aanbestedingsfase haalt Rijkswaterstaat de kleine dingen er soms uit. Ze leggen de focus vaak niet op de kleine dingen maar op de objecten met veel milieu impact. Bij de begin fase kijk je waar de meeste impact zit, meer naar het eind tellen de kleine dingetjes niet meer mee en gaat het om de grote objecten, hoe je daar een lagere MKI uit kan halen.

5: Koper is slecht gerepresenteerd en is niet goed gedocumenteerd. Daarnaast zijn er weinig proces chemicaliën in de gebruiksfase. De gebruiksfase (module B) is sowieso lastig aangezien er weinig processen beschikbaar zijn.

Wat zie je het liefst in een handleiding?

1: Het grootste probleem is de data in de productkaarten, traceerbaarheid van de informatie is moeilijk. Het zou beter inzichtelijk moeten zijn om te weten hoe je achter de juiste data komt. Sommige producten bestaan uit meerdere processen of producten. Het is vaak niet duidelijk hoe die onderliggende producten zijn toegepast.

Een ander groot probleem is dat het arbeidsintensief is om de webbrowser te gebruiken, deze is niet gebruiksvriendelijk. Het overzetten van data vanuit Excel is lastig al dan niet onmogelijk.

Een goeie vraag om naar te kijken is op welke vlakken wijken producten af die maar op 1 klein deel verschillen, transport afstand bijvoorbeeld. Er is dan niet genoeg informatie beschikbaar om te weten waarom de MKI waardes van een ogenschijnlijk zelfde product toch veel kunnen verschillen. Het probleem is het herleiden van de informatie, de beschikbare informatie is te weinig of niet goed gedocumenteerd om echt te kunnen bepalen waarom producten anders zijn.

2: Een protocol voor beide situaties, wat doe je als er geen data is en wat doe je als je niet kan schalen. Voor beide situaties een protocol of guideline ontwikkelen zodat iedereen daar hetzelfde mee omgaat. Het is lastig om te bedenken of dat protocol voor beide aanbestedingsfases moet zijn.

Er zou een vast protocol moeten komen om te kijken welke omrekenen factor toegepast moet worden per product. Hier worden ook geen vaste bronnen voor gebruikt. Er wordt wel gedocumenteerd en getoetst met de schalingsoplossing. Het grootste probleem is dat het hele product geschaald wordt naar 1 factor, alle dimensies worden naar dezelfde factor geschaald.

3: Een gestandaardiseerde methode voor alle gebruikers voor DuboCalc. Iedereen zou op dezelfde manier DuboCalc moeten gebruiken. Er zijn verwijzingsbladen die de NMD zelf heeft uitgebracht. Hier staat in hoe je met de problemen om moet gaan.

4: Ik zou graag een handleiding willen zien die de controle en toetsing van DuboCalc doet en begrijpt. Een checklist die je aan het einde van een project toe kan passen of je alles wel goed hebt gedaan en niks bent vergeten. Een uniform controle document of naslag werk. Welke hoeveelheden je moet gebruiken en hoe je ervoor zorgt dat dezelfde standaarden gebruikt worden. Een overzicht van alle data die wel gebruikt wordt vanuit andere LCA methode, een database daarvan. Met daarbij een bronvermelding en hoe en wat ze het hebben uitgevoerd en waarom. Dit is om ervoor te zorgen dat elke gebruiker niet elke keer het wiel hoeft uit te vinden.

Een guideline voor hoe je ervoor zorgt dat je het juiste product kiest en nadenkt over wat de opties zijn. Welke data moet je gebruiken en waar moet je naar kijken wat voor vervangend product je kiest.

Een uitgewerkt objecten bibliotheek zou ook handig zijn.

5: Een gestandaardiseerde methode met uitgangspunten en schaalfactoren en dichtheden zou handig zijn. De beperkte informatie omschrijvingen is matig en dit is een groot probleem. Je zou misschien naar de achterliggende data van Ecoinvent kunnen kijken. De dichtheid bijvoorbeeld moet vaak worden opgezocht waarna je het kan omrekenen.

Heb je nog andere tips voor dit onderzoek?

1: -

2: -

3: Je zou een aanbeveling kunnen maken aangezien de ontwikkeling van DuboCalc voor Witteveen + Bos wordt.

Aangezien DuboCalc over niet al te lange tijd onder contract van Witteveen + Bos komt zou je een aanbeveling kunnen schrijven. Daarnaast is het een idee om andere bureaus te interviewen. Aan andere gebruikers van de andere kant dan Witteveen + Bos vragen wat zij van die problemen vinden.

Interessant zou zijn om de NMD viewer te integreren met DuboCalc. Kijken hoe je de informatie van andere databases het best kan integreren met de informatie van de NMD.

De LCA database wordt gebruikt als je iets niet kan vinden, die zou je ook kunnen gebruiken. In SimaPro heb je alle materiaal type bijvoorbeeld, deze is opgemaakt uit data van Ecoinvent. Specifieke producten zoek je eerder op in Ecoinvent, hier staan rapporten in per materiaaltype.

4: Bedenk voor wie de handreiking moet zijn, dat moet duidelijk zijn want dat bepaald hoe het eruit gaat moeten zien. Je moet nadenken over of het een opstart gids is voor nieuwe gebruikers of voor het controleren van normale gebruikers.

Verschillende fases in het ontwerp proces nemen verschillende hoeveelheden producten in de MKI berekeningen mee. Bij een aanbesteding neem je minder mee maar wel preciezer terwijl je bij de begin fase van een project meer meeneemt maar alles minder precies om een generale schatting te krijgen.

5: Het is handig om een paar ontwerp rapporten en vergelijkingsstudies in te zien, daar kan je veel informatie uit halen.

Iets wat nog interessant zou zijn om uit te zoeken is of je aantal gerecycled materiaal in DuboCalc kan veranderen. We hebben een nieuwe leverancier die gerecycled materiaal kan gebruiken, meer dan het nu is in DuboCalc. De vraag is hoe je dat in DuboCalc gaat aanpassen.

10.4. Case studies

Four cases will be studied to understand the MKI determination process better. The original names of the projects have not been used and are replaced with Project one, Project two, Project three, and Project four.

Baseline measurement sustainability Project one

Project one is a road that needs to be redesigned. Many different design choices can be made in road design, product use, and material use. This report will calculate the MKI of the functional design for Project one to serve as a reference value for the designs (Bosch W. t., 2019). The functional design will serve as a reference MKI for the other designs and will not be focused on sustainable design.

First, the assumptions and scope of the project are determined. This means determining which materials and products to include in the calculation and stating general assumptions for the calculation. These are assumptions to clarify the choices made by the MKI executor, like available information on which the calculation is based.

Now the MKI calculation can start. The material information comes from the design phase or is retrieved otherwise when not available. When necessary, additional notes are written to explain the product choices made by the MKI executor. Information about the category, part, activities, amount, unit, DuboCalc product, and remarks is documented for every product. Most products have additional comments attached as an explanation for the choice made. All products are entered in DuboCalc, which calculates the MKI value and displays the data. DuboCalc can display the data in multiple ways, this case displays one graph as a pie chart with the ten most significant MKI contributors, and another graph shows the CO₂ emissions per phase. When the results are in, the interpretation/analysis of the result can start. Conclusions are drawn about which materials cause the most environmental damage. These are the products to be focusing on when trying to lower the MKI score.

Advisory report future proof design Project two

This report compares the environmental differences between two designs of Project two (ter Heijden & Hendriks, 2022). The report investigated the sustainability of the alternatives while disregarding the performance of handling the traffic. The research's cause is limiting road safety bottlenecks which requires an extensive redesign with high environmental costs at stake.

The following step is determining the project's scope and the environmental impact indicators that will be assessed: MKI, CO₂, material use, value retention and future proofness. In the method, the calculations of the environmental impact indicators are explained together with the assumptions and the explanation of the insecurities. The material used will be calculated based on quantity statements. A distinguishment is made between primary and total material use. Five experts estimations qualitatively determine the value retention, and the future proofness is determined by six experts. The study showed a slight difference in MKI (4%) and CO₂ (5%). The difference in material use is more substantial, with a difference of 21% to 28%. The value retention was not different for the two alternatives. The difference in future proofness was minimal, and both were not optimal.

At last, a test was conducted to see if the design choices align with the way Rijkswaterstaat considers the future and if it acts on its ambitions. These results will be taken into consideration during the remainder of the project.

What is surprising about this case are the five environmental indicators. The MKI has been brought to life to account for a project's environmental impact. The second and third indicators, CO₂ and material usage are implemented in the MKI score, making those indicators irrelevant. The future proofness of the project concluded that there was not much difference between the alternatives, but both were not optimal. This would indicate that another solution is desired since alternatives have some environmental impact, and it would be a shame if they have to be replaced on short notice. This report does not consider this in any way, which seems important.

MKI- and CO₂-calculations Project three

The municipality of Utrecht wants to aim for sustainability in Project three. This is done by aiming at low CO₂ emissions and MKI values in the tender phase of the project. This report describes a calculation of a reference value for the project, which will form the basis of the awarding criterion for the tender (ter Heijden & Doolaard, 2021).

The project's scope is determined, after which the assumptions for the calculations are stated. The information sources used are indicated in the references. The project has been split into three parts for clarity and a more straightforward result interpretation. The parts included in this research are where soil-, concrete-, and asphalt work takes place. After that, the material quantities are determined, the MKI and CO₂ calculations are made, and the results are analyzed. The results presented the top five materials with the highest MKI impact.

For this project, only the phases A1 to A5 are considered. This is the production and construction phase of the project. The other phases are not considered since this MKI value will serve as a reference value. Partially for this reason, the MKI calculation has been made in Excel because the MKI executor can calculate the production and construction phases separately.

In elaborating the MKI calculations, a column with remarks is presented. This column serves as an additional information/explanation source about a product. In the comments on three products, a question mark is noted. The remarks state a question about the product specification, which is missing. Besides, ten remarks contain an assumption, meaning the MKI executor did not know the specifications.

Reference value CO₂ emissions and MKI for the reference alternative for Project four

Commissioned by Rijkswaterstaat, Witteveen + Bos will design a fully circular design for Project four. For the degree of circularity, three considerations are taken into account, circular principles, emissions CO₂ equivalents, and MKI. This report calculates a reference scenario for the CO₂ emission and MKI. The new designs will be compared with the reference scenario to determine if and how much the sustainability measures contribute to the desired circularity (Schäffner, 2017). The report serves as a reference to conclude circularity later in the project.

Due to the MKI analysis being for a reference situation, circularity and innovation in materials are not being considered. The table with materials and used DuboCalc items shows that products are missing from the NMD. For example, the material Beton C28/35 nat/droog, dooizouten/ chloride XD3 is required, but the NMD does not contain that product. Instead, the product Betonmortel C30/37 (CEM1) is used. This is concrete with different material properties but the best approximation, which is why it is chosen. The report ends by mentioning the next steps in the design process. The most critical design decisions are mentioned for the subsequent phases.

10.4.1. Conclusion

The four cases that are analyzed all followed the same structure. First, determine the goal, describe the method, state the assumptions, and the scope after which the MKI calculation can start. The reports end with a conclusion and sometimes a recommendation or follow-up design plan. The reports had one of two goals: determining a reference MKI value for comparing the final designs and calculating an MKI alternative for a project. In the studies where project reference values were calculated, the innovation and circularity part of DuboCalc was not included. No attention was given to design sustainable.

A reoccurring point was the available information on products and materials. The MKI executors do not always have enough information available and have to make assumptions. This is not a big problem for calculating reference scenarios, but when real MKI alternatives are calculated, this is a bigger problem.

The scope of the project is partially dependent on the design phase. "Not all parts were detailed enough to be included in the calculation. The following items are excluded from the scope of the calculation due to missing quantities or material specification" (Bosch W. t., 2019). The same applies to the other projects. When not enough information is known about a product, it is not considered in the MKI calculation.

The only case study found in the Witteveen + Bos DuboCalc is Project two, while being an outdated version. This project contains many products, but the resulting MKI values are not the same as those in the report. Besides, the report states that for the calculation of the MKI, DuboCalc 6.0 from 17-11-2021 is used (ter Heijden & Hendriks, 2022). Project two in DuboCalc started, and was last edited in September, which cannot be correct. The other case studies also could not be found in DuboCalc. Either the projects have been removed from DuboCalc, or the Excel file is used, which is the most likely option. It may be a coincidence that the four cases studied are not in the project library of Witteveen + Bos. It is more likely that Witteveen + Bos uses the Excel file for the 'real' MKI calculations.

10.5. Functioning MKI determination process

Witteveen + Bos, among others, experience that the program and the MKI determination system are not functioning as they should. Reports about DuboCalc and the MKI system are written, discussing its functioning and making recommendations.

10.5.1. DuboCalc and CE (Circular Economy) - final report

In 2018, Witteveen + Bos published a document with functional specifications for the adjustments that must be made in DuboCalc to improve the circular economy of the construction sector in the Netherlands. "This functional specification must be able to form the basis for an assignment to the developer of DuboCalc" (Schaffner, Schilder, van Leeuwen, & Scholtes, 2018). Witteveen + Bos mentions multiple desired additional functionalities, of which the following seven are most important:

1. Calculate material efficiency within DuboCalc
2. Insight into modules A to D
3. Make transparency and distinction between phases, processes, and materials transparent
4. Making insight into what is included in the item card
5. Make material balance transparent (transfer LCA for administrators) and include raw materials passports, both of the current situation (as-is) and in the future situation (as-built)
6. Adjusting the life span of the product on a product card
7. Calculating with multiple life cycles and allocation

Currently, none of those desired additional functionalities is available in DuboCalc.

10.5.2. Feasibility and enforcement of MKI values

Contractors try their hardest to design projects with low MKI values. In a case for ProRail, two contractors went head-to-head in a tender battle. One contractor came up with a much lower MKI value and got the contract. The losing party filed a case against the winning contractor for an irrational bid to invalidate the tender (Chee, 2019). The first argument was that the winning MKI was raised after a few questions from the information note of ProRail, which does not give confidence about the legitimacy of the MKI. The accusing party hired an expertise agency to research the lowest possible MKI for this project. They concluded a higher MKI than the winning MKI. However, the judge did not find these reasons enough to invalidate the tender. The losing party wanted to look into the other party's MKI, which was not allowed. Company sensitive information does not have to be shared with the other contractors, only with the outsourcing party. Concrete information about the winning MKI was unavailable, making it hard to sow reasonable doubts and challenge the winning MKI.

When a contractor cannot conform to its claimed MKI value, it can receive a fine from the outsourcing company. Another case for an asphalt paving contract showed a loophole. A contractor won the tender with a low MKI value. After research, it was concluded that the contractor could never comply with its claimed MKI and calculated the fine into its budget (Nuijens, 2020). The contractor calculated that with the fine, the contract would still be profitable and went ahead with it.

Enforcing the claimed MKIs is a crucial last step of the contracting process based on MKIs. The claimed MKI value should become a contract requirement after the tendering phase. According to Pianoo (sd), an expertise center in tenders, “the purchasing organizations are hesitant in the imposition of sanctions” (Prinssen & Rademaker, 2020). This can lead to contractors tendering with unrealistic low MKI values to get the contract. The cause of this problem is that “in principle, a contracting authority may rely on the correctness of a tender. Only if there is reasonable doubt as to whether the tenderer does meet the requirements, a contracting authority is obliged to conduct a further investigation” (Dijk, 2021). This means when the outsourcing party does not have doubts, it can assume the correctness of a registration. The registration does not have to be checked and is trusted to be valid. A party who lost the tender due to another party having a lower MKI can find the other tender invalid. To prove this, they have to come up with enough evidence of the MKI being inaccurate to stir up a reasonable doubt. This has to be done without looking at the data of the MKI calculation. Only when reasonable doubt exists at the outsourcing company they have to investigate the MKI.

10.6. Missing literature

Not all desired literature was found to make the research more conclusive and back it up. This chapter discusses the literature that would benefit the research but was not found.

Proof of MKIs being inaccurate. The research, Milieuprestatiebepaling van recycling en hergebruik van bouwmaterialen, concluded that due to different choices of users within the LCA method, environmental impacts of products can differ up to 50% in module D. This leads to believe that MKIs can be inaccurate and different depending on the executor. Still, no proof of this can be found. A possible explanation is that third parties interested in researching this cannot access the data required for this research. This also happened in the case C/16/470268 / KG ZA 18-706 in the central Netherlands Court (de Rechtspraak, 2019). The accusing party stated that “VolkerRail’s registration with regard to the MKI discount is unrealistic and that the provisional award decision is insufficiently substantiated” (de Rechtspraak, 2019). During this process, the accusing party wanted to check the MKI calculations of the winning party. According to the judge, this was turned down because company confidential information does not have to be disclosed. This is a case where the MKI might have been not accurate, but the other party could not prove it. When there is no reasonable doubt the MKI value is unreal, the outsourcing party can, in principle, assume the correctness of a registration. This means MKIs do not have to be checked when no reasonable doubt is present.

DuboCalc is currently under maintenance, and not all functionalities are available. There used to be an option of scaling products within DuboCalc, but this has been unavailable for some time now. The same counts for transport distance. Some products had the option of changing the product transportation distance. These options have not been available for quite some time now, and according to Aardenburg (2022), they should be solved on short notice. Still, it cannot be said with certainty due to the dependence on founding Nationale Milieudatabase when this is. The scaling function would be helpful to see how the Nationale Milieudatabase wants products to be scaled in DuboCalc.

The data from category three may not be representative. Category three is the largest data contributor to the GWW sector (92%). This is uncertified data under the management of the NMD. This data gets an additional increase on its MKI value of 30% because experience shows that untested environmental profiles often indicate too low of an environmental impact. After all, the inventory data is less complete (Stichting Nationale Milieudatabase, 2022). No in-depth explanation or calculation of this 30% rule could be found anywhere. Besides, it does raise questions about the accuracy of category three data. How can all data be ‘equally as bad’ that they deserve a 30% raise? This cannot be good for the accuracy of the MKI value.

The most significant cause of all challenges in this research is missing data. Additional information on how the EPDs for all materials have been made up and more specifications of the products are desired. Tracking this information is complex and does not work most of the time because much data is company sensitive and is not accessible. The in-depth documents on how the MKIs are set up would be useful. This is not possible for category three since there is no in-depth MKI determination document because it is based on the Ecoinvent database.

No literature was found on how to scale products in MKI calculations correctly and what to do when a product is missing. Stichting Nationale Milieudatabase leaves that up to the MKI executor to determine. As shown earlier in this report, there are certain phases or elements of which products consist that do not scale proportionately with the product itself. However, it is not known how these elements or phases should scale. This probably depends on the product's specifications that must be scaled. No standardized method was found on how to deal with these scaling issues, like the interviewees stated that would be useful.

10.7. Background on MKI – DuboCalc - NMD

MKIs are determined with the program DuboCalc. This method was developed by Cenosco and Royal HaskoningDHV and commissioned by Rijkswaterstaat. The method uses the NMD as input for the MKI calculations. The SBK (StichtingBouwKwaliteit) manages the NMD and updates the “Bepalingsmethode”. Figure 3 is an overview of the Bepalingsmethode MKI/MPG.

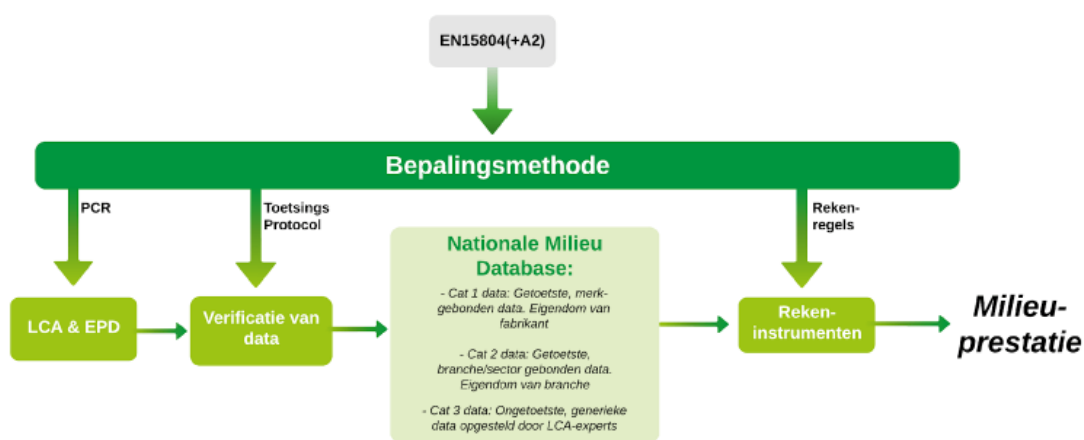


Figure 3: overview of the “Bepalingsmethode” (Stichting Nationale Milieudatabase)

All elements and products in the NMD are in one of four main product groups: construction, equipment, finishing, or painting (Dijkstra, 2019). These groups represent a function, all elements and products are in one of the four groups. The products in the NMD also belong to categories one, two, or three. Category one is proprietary data products assessed by an independent qualified third party according to the NMD testing protocol. Category two is unbranded data, tested by an independent qualified third party according to the NMD testing protocol, mentioning the participating companies and disciplines. The third category is unbranded data which is the property of and managed by the NMD. The NMD testing protocol does not test this data. This category is created to serve as backup values when the products are not available in categories one or two (Stichting Nationale Milieudatabase, 2020) .

Each product contains an EPD (Environmental Product Declaration) which is a summary of the LCA of the product and contains all relevant information the MKI executor needs to know. An LCA is the factual analysis of a product's life cycle in terms of sustainability (Golsteijn, 2020). The EPD follows the rules of the EN-15804(+A2). This is a European standard based on the “Bepalingsmethode”. The data available that has not passed the test of the “Bepalingsmethode” has not been verified by an LCA expert. This is data from category three. The EPD of these products are made from the Processendatabase. This is an LCA database of materials, products, and processes based on another database, Ecoinvent (Nationale Milieu Database, 2022). This serves as a base of the EPDs of products from category three. Within the LCA, four life cycle categories are distinguished, describing the specific phases' environmental impacts as seen in Figure 4. This figure shows the environmental impact of a product in all phases of its life cycle.

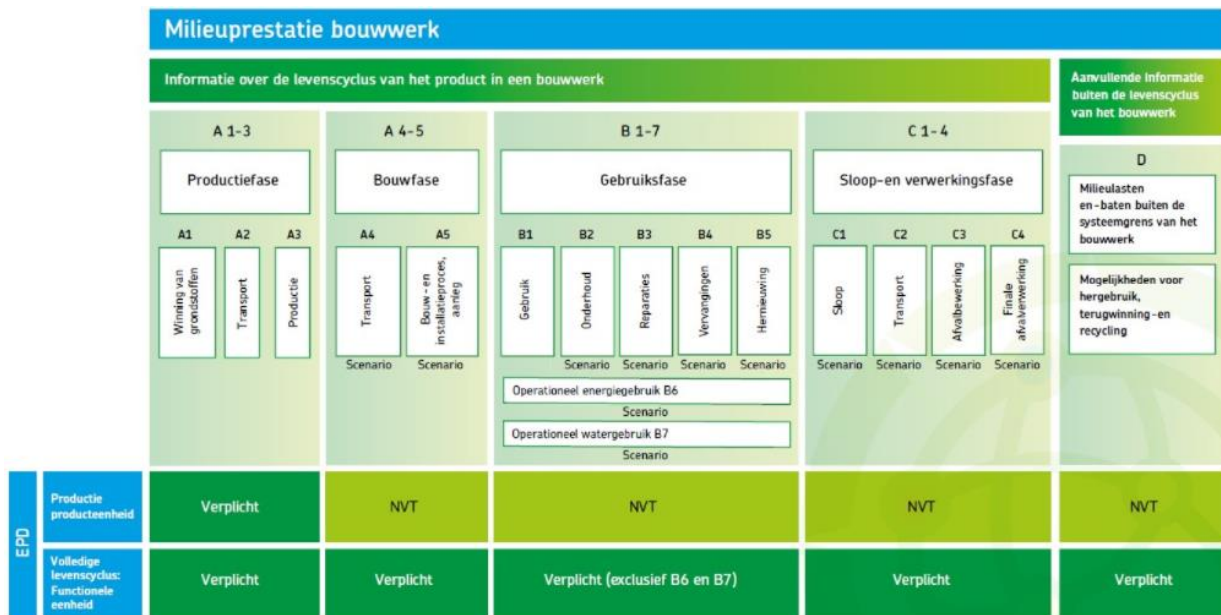


Figure 4: overview of the life cycle phases (Stichting Nationale Milieudatabase, 2022)

The MKI is constructed from eleven environmental impact categories. These categories all have a weighting factor. CO₂ emission on its own is the largest contributor at about 50% of the total impact (Klauw, 2018). The result can be seen as the monetary value of the project's environmental damage over its entire life cycle.

Once all products and processes are entered in DuboCalc, the MKI can be calculated. The program presents graphs showing which products, materials, and phases have the most significant environmental impact. The goal of the SBK is that companies use these results to analyze the environmental impact and where they can undertake action to reduce the MKI.

10.8. Example disproportionate scaling method

This is an example of scaling using scaling formulas of the "LCA Rapportage category three data Nationale Milieudatabase" chapter 34, lighting (Sant Verde & SGS Search, 2021). This report determines the scaling formulas of two types of light posts in the NMD, aluminum, and steel. The specifications of the light posts are retrieved from <https://www.ledlampshopxl.nl/> and supplemented with information from tenderned.nl. The statistics of the light posts are stated in Table 9.

Table 9: statistics light post (Sant Verde & SGS Search, 2021)

	Lengte mast (meter)															
	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	
Al (kg)	12		16		41				100						224	
Fe (kg)	23		45			88			126						382	

When this is entered in Excel, the following formulas are calculated. Based on the best R² value and the way the graph behaves at larger sizes of light posts, the aluminum light post used the power function, and the steel light post used the exponential function.

Table 10: formulas calculated by Excel, (Sant Verde & SGS Search, 2021)

	Exponentieel	Lineair	Logaritmisch	Macht
Al	0,957	0,965	0,844	0,973
Fe	0,981	0,910	0,757	0,982

For aluminum $y=0,55 \cdot X^{2,07}$ & for steel $y=12,95 \cdot e^{(0,19 \cdot X)}$

This resulted in the following graphs.

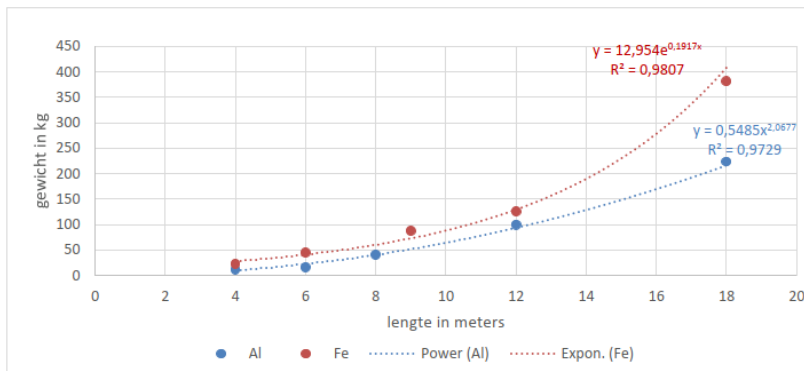


Figure 5: scaling formula graphs (Sant Verde & SGS Search, 2021)

10.9. Circular construction products in the GWW sector

Rijkswaterstaat wants to encourage sustainable construction. Currently, it is clear that not enough secondary building materials are becoming available in the Dutch civil engineering sector to meet the current construction needs circular. That means we have to work harder to develop and use renewable materials. This should also be integrated into DuboCalc for the MKI calculations. According to Ministerie van Infrastructuur en Waterstaat (2022), the five most used construction materials are soils, asphalt, concrete, steel, and wood. The association of construction and infrastructure companies in the Netherlands adds ceramic building products and sand-lime brick to the list of most used and essential material groups in the GWW sector (Peschie & Stichting Stimular, 2019). Using biobased materials increases the circularity of construction projects. These are some construction methods and materials used and developed in the civil engineering sector (Bruggink, sd). Stamped earth, rammed earth, or loam massif construction is a method in which materials such as sand, clay, and gravel are used and compressed into a solid floor or wall. The second material is loam bricks. These are not heated bricks, reducing emissions in the production process. It consists of a mixture of clay, soil, and natural fibers (straw, sawdust), which is pushed into a mold. Then the stone dries and hardens by itself without an oven. The third is straw. This is a by-product of farming and therefore, cheap and widely available. Just like wood, straw stores a lot of CO₂, costing relatively little energy to process. The fourth biobased material is hemp. This crop grows almost anywhere in little time and has solid fibers. Like concrete, it can be poured into a mold, sprayed, stacked in handy blocks or processed in prefab walls. Finally, the best performing biobased material with multiple functions which is wood. It is used for timber frames, solid timber constructions, and system timber constructions (Bruggink, sd). These methods show the diversity of biobased materials, which are not in the NMD yet, but are (or will be) used.

10.10. Data gathering tips

As mentioned in the interviews, the lack of available data on product cards is a problem. A problem of this lies with company-sensitive data from category one which will not be shared. Category two only consists of ten products. Products from category three are based on other LCAs and did not receive an accurate, in-depth LCA analysis, meaning the data does not exist. This chapter contains tips on gathering data on products that have to

be scaled or cannot be found in the NMD. This data research is a time-consuming process. The MKI executor has to choose if it is worth the time and effort since there is a chance that it does not work out.

10.10.1. Databases including EPDs of products

The lack of product cards in the database is because the validation is too strict for an LCA to be included in the NMD (Oostdijk, Dreef, & Schellekens, 2019). Several experts state that the number of category one and two product cards can be enlarged by working better in the European context. For example, Germany (IBU), America (UL environment & SCS Global), France, and other countries that developed a total of 5.000 EPDs which can be implemented (partially) in the NMD. This also would indicate that these databases could be used for researching products. Databases that could be used for EPDs on products are stated in Table 6.

10.10.2. Researching data

In the case of category one data: research the company for data on the product. Perhaps they produce the product, and specifications are available online. Another option is to contact the company that owns the data and ask for information. Category two is data that is unbranded and representable for the Dutch market. Market research can be done to find represent information on the product. An example is the "LCA Background Report for Industry Representative Dutch Asphalt Mixtures 2020" (Schwarz, et al., 2020). This report describes the environmental profiles of 19 industry-representative asphalt mixtures. This information is available to the public and can be used when analyzing asphalt mixtures.

10.11. Margins of errors when scaling products

This chapter shows the elaborations on the three different ways scaling cause inaccuracies in the NMD.

10.11.1. Disproportionate scaling examples

A light pole with a length of 4 meters weighs 23 kg (SpeciShops, sd). The same light pole, but with a length of 6 meters, weighs 45 kg. A length increase of 1.5 times comes with a weight increase of 1,96 times. This shows that the material used in light poles does not scale proportionately with the length and thus also the MKI.

Another example is reinforced concrete. The reinforcement in the concrete does not span the entire length of the concrete but a bit less. For a short slab of concrete, this means the reinforcement spans about 90% of the length of the slab, while when taking a massive slab of reinforced concrete, the reinforcement percentage approaches 100%. When scaling, this should be a concern since the reinforcement in the concrete is a substantial contributor to the MKI. There are two kinds of products with reinforcement in the concrete. The first is a product in which the reinforcement is integrated into one element with the concrete. The second option is when the reinforcement is an element on its own.

10.11.2. Element scaling Examples

Bridges

Two steel bridges will be compared and two concrete bridges will be compared. The bridges will most likely be scaled on length in the MKI calculations, so that is where they will be compared. With the available information on the products in the NMD, the MKI maintenance per ton bridge can be calculated, as shown in Table 11. Since the bridge's length is the dimension that will most likely be scaled upon, this calculation has also been done for the MKI per length bridge, which can be found in the table below.

The only missing information is the specific weight of the concrete slabs. The material is prefabricated concrete

slabs, a rule of thumb according to onlinebetoncentrale (2019) is that the density of concrete is 2400 kg/m³, which is used in the calculations.

Table 11: four bridges wit specifications

	Span (meters)	Lifespan (years)	MKI use phase per FU	MKI use phase per ton	MKI use phase per meter bridge
Small steel bridge (piece)	15	100	526	58,2	35,1
Steelconstruction: steel arch bridge (ton)	160	100	27,0	54	37,5
Bridge part of concrete slabs (m ²)	6	100	18,9	26,25	56,7
small concrete bridge (piece)	15	100	495	6,59	33

Oddly, these MKI per use phase of the steel bridge correspond. The steel arch bridge is calculated for a length of 160 meters. The small steel bridge is two meters wide according to the general information of the product. One would expect that the width of a bridge that is 160 meters instead of 15 meters would be much larger, and a more significant difference in MKI use phase per meter bridge would be observed, which is not the case.

The results of the concrete bridge are much more skewed and show a significant difference in MKI. This difference can be due to the bridges not being as wide, but this cannot be known for sure since that information is not available in DuboCalc. For example, a concrete bridge of 10 meters is required. With the elements available in DuboCalc, the MKI executor has two choices. Take the 2/3 small concrete bridge of 15 meters or take 10/6 bridges part of concrete slabs. When this is calculated, the MKI for the use phase for the small concrete bridge is 330 MKI. For the bridge part of the concrete slab, it is 567 MKI. This is a significant difference for just the use phase of the bridge.

Spindle valve

The NMD contains three spindle valves with different dimensions in Table 12.

Table 12: spindle valves

Product	Weight (kg)	demolition and processing phase	construction phase	MKI without 30%
Stainless Steel Plastic Spindle Valve, small 250mm	32	3,62	83,5	189,1
Stainless Steel Plastic Spindle Valve, middle 400mm	64	1,88	228	483,8
Stainless Steel Plastic Spindle Valve, large 600mm	205	2,76	533	1115

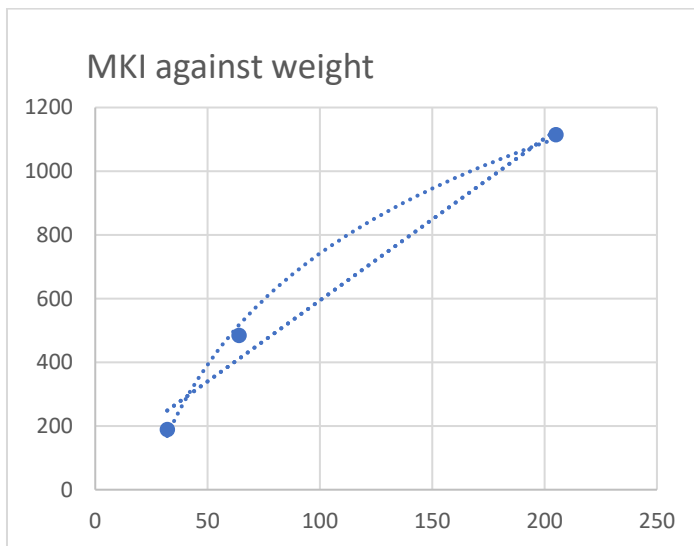
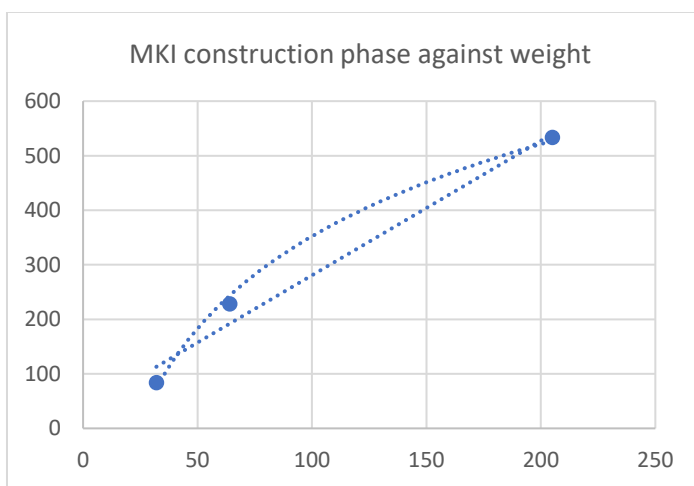
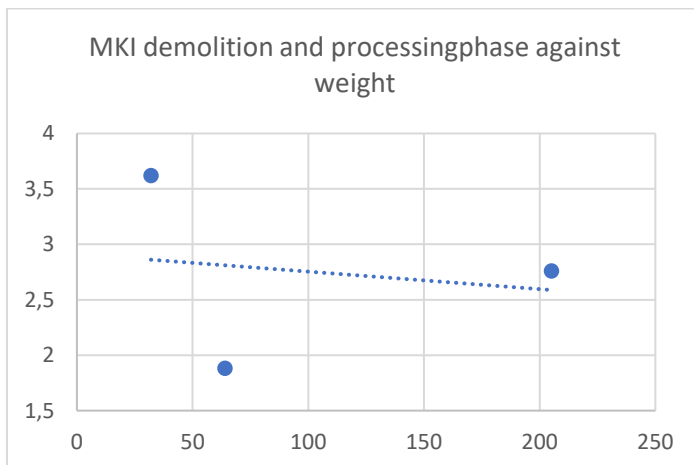


Figure 6: MKI demolition and processing phase against weight

Figure 6 displays the demolition and processing phase against the product's weight is not what is expected. The MKI of the middle-sized spindle valve is much lower than the others. Due to little available information, it could not be said with certainty why that is the case. The other two graphs show that the MKI does not increase

proportionately when the weight increases. The MKI increases less over time as the weight/size of the product increases.

10.11.3. Phase scaling examples

Inspection pit prefab concrete

The first example is an inspection pit made of prefabricated concrete. There are three of these products available in the NMD. The product is the same, but the size varies. The products consist of three elements each, two elements for the construction of the inspection pit and one element containing the processes A5 and C1. A5 is the construction and installation process of the construction phase, and C1 is the demolition process. The three products with the estimated volumes and the percentage of MKI contribution the processes A5 and C1 have been stated in Table 13. The volume is estimated similarly for each inspection pit based on the available information.

Table 13: percentage of MKI contribution inspection well

Product	Estimated volume mm ³	MKI
Inspection well prefab concrete 800x800x1100mm, 15mm wall thickness	704.000.000 - 634.403.000 = 69.597.000	94,6
Inspection well prefab concrete 1000x1000x1200mm, 15mm wall thickness	1.200.000.000 - 1.100.853.000 = 99.147.000	126,8
Inspection well prefab concrete 2000x2000x2400mm, 20mm wall thickness	9.600.000.000 - 9.066.176.000 = 533.824.000	1129

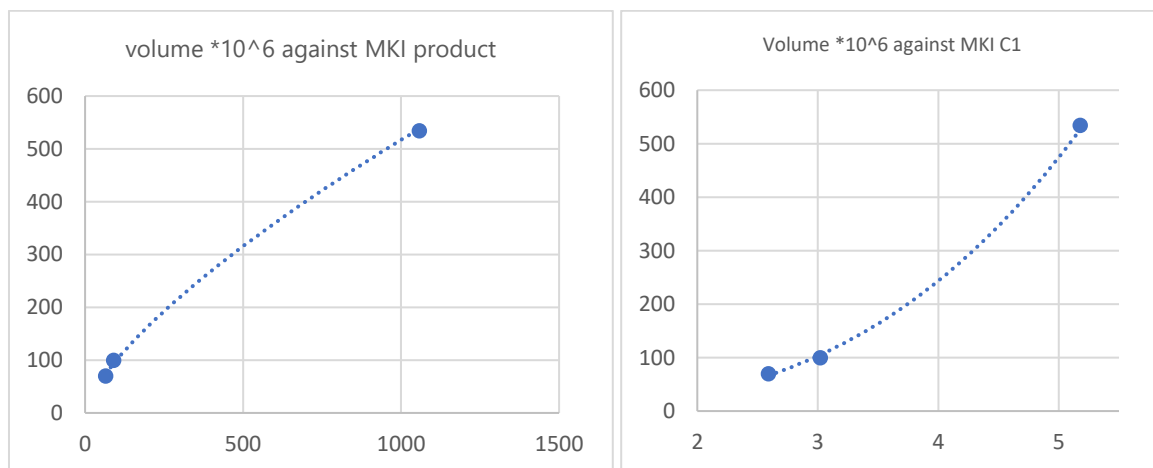


Figure 7: Volume (weight) of the product against the MKI (whole product), processes A5 and C1, and MKI process C1.

Error! Reference source not found. Figure 7 shows some results of product sizes against MKIs. The left figure shows the volume against the MKI impact of the entire product. This is also calculated for process C1 (demolition) against the volume product. The right figure shows that the demolition process does not scale proportionately with the product volume. This shows that as the volume of the product increases, the process C1 contributes relatively less MKI than the volume.

Weir valves

The second example from the NMD is three weir valves, the same product but with different dimensions and thus different MKIs. The products consist of two elements, the weir valve and a crane. The crane contributes the same MKI value to all three products even though the weir valves differ in size. This means the percentage of MKI contribution of the crane is different for each weir valve. The results can be seen in the table below. The NMD also contains three outflow trays with different dimensions, of which the data can also be found in Table 14.

Table 14: specifications on three weir valves and outflow trays in the NMD

	total MKI	Crane MKI	Percentage crane MKI
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Weir valve 1000*600 mm	3150	49,7	1,58
Weir valve 1500*800 mm	4653	49,7	1,07
Weir valve 2000*1200 mm	7752	49,7	0,64
	total MKI	Equipment MKI	percentage equipment MKI
Outflow tray, 1000 mm	196	78,3	39,9
Outflow tray, 600 mm	126	44,8	35,6
Outflow tray, 400 mm	102	44,8	43,9

The environmental impact of the crane does not scale proportionately with the size of the weir valve. This is also shown in the graph below. This graph shows that the MKI impact of the equipment does not scale proportionately with the size of the product. This is not a problem for the weir valve since multiple product dimensions are available, so the desired size is probably available. However, this is a problem for products not as well represented as the wire valve.

When a weir valve twice the size is required, it would be logical to fill two valves in DuboCalc. Actually, this would not be the case because DuboCalc would also scale the crane twice, while the crane should not be scaled twice. The percentage of equipment MKI of the outflow tray is also not proportionate, as seen in Figure 8.

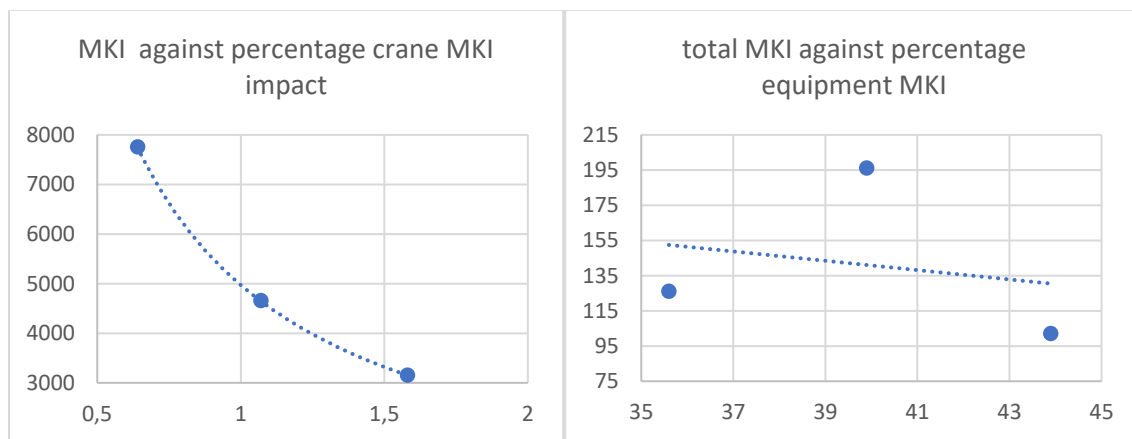


Figure 8: MKI product of different sizes against MKI crane and equipment

10.11.4. Scaling examples with functional units

Table 15 shows products scaling in multiple dimensions.

Table 15: products scaling in multiple directions

product	traffic sign	steel bridge	sheet pile	Sheet pile Twinwood - Faunawood	Foundation floor, fiber reinforced	inverted prefab T girder, span 25 meters	Steel amphibious screen	Cement bentonite post
FU	piece	piece	piece	m ²	m ²	m	m	m
number dimensions to scale	1 -d	2 -d	3 -d	2-d	3-d	1 -d	2 -d	3 -d
explanation	number of traffic signs	length and width bridge	length width and depth sheet pile	m ² of the sheet pile	scaling area and depth	span of the girder	length and width of the screen	length and diameter of the post (diameter change is in 2 dimensions)

10.12. Method of developing a guideline

The guideline that is developed for the scaling product challenges goal is to recommend how to scale products and deal with missing products. The guideline should make the user think about if it is the right way before solving it.

The research "Advanced Human-System Interface Design Review Guideline" aims to "develop a general approach to advanced HSI (human-system interface) review and the human factors guidelines to support NRC (Nuclear Regulatory Commission) safety reviews of advanced systems" (O'Hara, et al., 1994). The document, among other things, describes what kind of guidelines exist and where to use which ones. It also states rules and instructions on how to design a human-system interface.

The first thing to do is to determine which display format to use. Examples of display formats are continuous text, lists, speech displays, flowcharts, tables, data forms, mimics, diagrams, maps, histograms, bar charts, pie charts, and graphs (with scatterplot). Figure 9 shows the display formats for representative user tasks.

Representative Task	Format	Condition for Appropriate Use
Comprehending Instructions or General Descriptions	Continuous Text	General
	Lists	Series of related items
	Speech Displays	User's attention not directed toward text display
	Flowcharts	Sequential decision process with no tradeoffs
Examining and Comparing Individual Numerical Values or Text	Tables	Detailed comparisons of ordered sets of data
	Data Forms	Detailed comparisons of related sets of data items from separately labeled fields
Examining Functional Relationships of Components of a System	Mimics and Diagrams	General
Examining Spatial Relationships of Objects or Places	Diagrams	General
	Maps	Geographical Data
Examining and Interpreting Patterns in Numerical Data	Bar Charts	Single variable viewed over several discrete entities or at discrete intervals
	Histograms	Frequency of occurrence viewed at discrete intervals of a single variable
	Pie Charts	Relative distribution of a single variable over several categories
	Graphs	Two or more continuous variables
	Graphs: Scatterplot	Spatial distribution of data within a coordinant system

Figure 9: tips for guideline design (source: O'Hara, et al., 1994)

This figure contains the display formats and the condition for appropriate use. Based on this figure, the flowchart display format: "sequential decision process with no trade-offs", fits best.

"Flowcharts can add structure to complex problem solving by illustrating a set of discrete decision points. With a flowchart, a user is given specific steps to follow in solving a problem, helping to ensure that all relevant factors are considered" (O'Hara, et al., 1994). That last point is essential, ensuring that all relevant factors are considered. Forgetting a simple point in the MKI determination process can happen since there are many different products. Those products behave differently, so when designing, it should be watched that all products are considered in the guideline. According to Prasanna (2022), the advantages of a flowchart are: easy to make, effective communication and easy to understand, synthesis becomes effectual, debugging becomes possible, logic can easily be interpreted, analysis becomes effective, and mistakes can easily be identified. With the program, "LucidCharts", making a flowchart is easy and can be adjusted later. The advantages of this method that it would be judged on are all present. Easy to use, easy to understand, complete consideration of the subject, and future proof.

According to O'Hara, et al. (1994), there are seven information display points of attention for a flowchart:

- Logical ordering of decision options
- Single decision at each step
- Consistent ordering of decision options
- Availability of supplemental information
- Conventional path orientation
- Flowchart symbol set

O'Hara, et al. (1994) also explains general points of attention when designing a manual. The following are important for this research:

- Conservative use of color
 - Blue and white are colors with an advisory sociated meaning
 - Red is associated with alarm state
 - White is a good contrasting background-color
 - Green is in line with the sustainability goals but gets a poor attention-getting value
 - Use minimum color differences

- Use a legend
 - define colors
 - define shapes
 - define abbreviations
- Maximum of three size variations for symbols
- General information that should be included
 - Title
 - Statement
 - Scope
 - Additional information
 - Sources

The rules and points of attention have been followed and applied with two exceptions. One rule, making single decisions at each step, has been disregarded at choice number four, the users must choose between three options.