The potential benefit of industrial construction in CO_2 savings

A comparison with traditional construction and possibilities to reduce the environmental impact of industrial construction

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ABSTRACT: The Dutch housing sector aims to build 100,000 houses annually, but at the same time to reduce its environmental impact by becoming climate-neutral in 2050. Industrial construction, proved to be faster and more cost-effective compared to traditional construction, is considered a potential solution. It is also perceived to be more sustainable. However, to the authors' knowledge, this has not been quantitatively researched anywhere.

The MPG (Environmental Performance of Buildings) calculation is used to calculate the environmental impact in the construction sector. The MPG score is expressed in euros per square meter gross floor area per year (€/m^{2}bvo annually). However, the hypothesis is that the MPG calculation is not developed enough to accurately calculate the environmental impact of industrial constructed houses.

This research identified and quantified the insufficiently reflected topics in the current MPG calculation that could lead to differences in the environmental impact between traditional and industrial construction. The aim is to determine the potential benefit of industrial construction in CO_2 savings by comparing those quantified topics between traditional and industrial construction.

The main methods conducted in this research are literature review, semi-structured interviews, company visits, case studies and the creation of models using Excel.

This study specifically examines the Production and Construction Phase of the MPG calculation, emphasizing that results may vary with a broader scope. Limited data availability led to assumptions in model creation and recommendations are based on interviews with a restricted number of participants due to time constraints, potentially impacting result generalisability.

Results indicate that the environmental impact of transport and machinery, construction waste and the construction of the housing factory is currently not sufficiently reflected in the MPG calculation, especially in the Construction Phase. Quantifying those differences reveals that industrial construction, for this scope, produces 25-53% fewer CO_2 emissions compared to traditional construction.

To reduce the environmental impact of industrial construction, the government should enforce stricter regulations on sustainable buildings and monitor the MPG calculation regulations. The National Environmental Database (NMD) could improve the MPG calculation for industrial construction and could improve its communication with construction firms. Clients could invest in sustainable projects and challenge construction firms to reduce their environmental impact.

Industrial construction firms could invest in sustainable materials (materials with a reduced environmental impact compared to their traditional alternative, for example, biobased or secondary materials), explore alternatives to diesel trucks, implement renewable energy sources in the housing factory and possibly further optimise waste management in the housing factory. Finally, it is important to establish accurate Environmental Profiles for their produced elements.

KEYWORDS: Construction sector, industrial construction, MPG, transport and machinery, construction waste, housing factory.

1. INTRODUCTION

The construction sector in the Netherlands is facing challenges. It needs to become more sustainable by reducing GHG emissions by 55% in 2030 [1] and developing a circular economy in 2050 [2]. Conversely, the government aims for an annual output of 100,000 houses [3].

> *Traditional construction* takes place on the construction site, construction materials are transported from suppliers to the construction site [8]. *Industrial construction* means elements are made in housing factory and transported to the construction site [9]. *Hybrid construction* is a combination of both methods.

As industrial construction is perceived to be faster, cheaper [4] and safer [5] compared to traditional construction, it is one of the solutions to these challenges according to the Dutch government [6].

> The MPG consists of four modules: A, B, C and D. A calculates the impact of the *Production* (A1- A3) and *Construction* (A4-A5) phase. B calculates the impact of the *Use* phase. C calculates the impact of the *Demolition and Processing* phase and D calculates the impact of *reuse/recycling opportunities* [10].

The perception is also that industrial construction is

more sustainable, but this has not been quantitatively tested anywhere to the authors' knowledge.
To determine to which extent industrial construction is more sustainable than traditional construction, the MPG is used. However, there are many criticisms and perspectives on the extent to which the MPG drives sustainability [7].
This study aims to determine the potential benefit of industrial construction in CO_2 savings compared to traditional construction by making a comparison between the currently insufficiently reflected components in the MPG calculation. Therefore the main question of this study was: "*What is the potential benefit in CO_2 savings of industrial construction compared to traditional construction when focusing on the currently insufficiently reflected topics in the Production and Construction phase of the MPG calculation*"

2. BACKGROUND CURRENT MPG CALCULATION

Based on the EN 15804 method, Life Cycle Analyses (LCAs) for construction products are determined. Those LCAs result in the environmental impact of different (11+) topics, for example, human toxicity, acidification or climate change (GWP-100), called Environmental Impact Factors [10].
For every Environmental Impact Factor, a shadow cost was determined. Those shadow costs result in an MKI (Environmental Costs Indicator) in €/m^2 for a certain construction product [10]. The National Environmental Database (NMD) collects those MKIs in the so-called Environmental Profiles.
Adding those MKIs for all the construction products used in a house divided by the expected lifetime and the gross floor area (bvo) of the house results in the final MPG score (Figure 1) in €/m^{2}bvo annual [10]. The lower the MPG score, the lower the environmental impact [10].

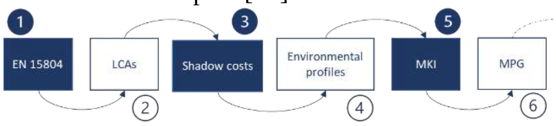

Figure 1 The roadmap to the MPG score

3. METHODOLOGY

This section aims to describe the research phases, the system boundaries and the methods conducted in this research.
Phase I aims to identify the differences between traditional and industrial construction that are currently perceived to be insufficiently reflected in the MPG and to provide an adapted MPG calculation that includes those differences.
Phase II aims to quantify the differences identified in Phase I based on the adapted MPG calculation. This will allow for a fair comparison between traditional and industrial construction, and determine the potential benefits of industrial construction in terms of CO_2 savings.
Phase III aims to provide recommendations for key stakeholders in reducing the environmental impact of industrial construction.

This study solely focuses on the Production and Construction Phase of the MPG calculation. Appendix A presents the system boundaries as applied in this research. This is based on the adapted MPG calculation (Chapter 4).
Phase I focuses on the Production and Construction Phase of traditional and industrial construction. Phase II zooms in on the Construction Phase of both construction methods. Phase III is about the Production and Construction Phase of industrial construction. Appendix A provides an overview of the system boundaries as conducted in this study.
The methods used in the different phases are among others: desk research, semi-structured interviews, company visits, case studies and the creation of models in Excel.

4. RESULTS PHASE I

This section provides the results of Phase I: Identifying the differences between traditional and industrial construction that are currently perceived to be insufficiently reflected in the MPG and providing an adapted MPG calculation.

4.1 Identified differences

During the interviews, several issues with the MPG method were mentioned. This chapter will describe the issues that are relevant to this study.
First, the Construction Phase modules in the MPG calculation are frequently empty, resulting in the environmental impact of Construction Phase activities being left uncalculated [7].
Secondly, the data quality of the Environmental Profiles collected in the NMD could be improved, particularly for sustainable and manufactured elements. More accurate Environmental Profiles are needed, but this process is time-consuming and costly [7].
Lastly, there are currently no differences visible in the MPG score when the same materials are used but a different construction method is conducted [7].
The fact that there are currently no differences visible in MPG scores is due to certain topics that are currently insufficiently reflected in the MPG calculation [7]. Since the impact of activities during the Production Phase is often well-calculated, these topics are related to the Construction Phase.
Results of interviews suggest that the following topics require more precise calculations to make a fair comparison between traditional and industrial construction [7]:

- Transport and machinery (+);
- Construction waste (+);
- The construction of the housing factory (-).

As this study examines the potential benefits of industrial construction in terms of CO_2 savings, a plus (+) indicates an expected positive effect for industrial construction and a minus (-) indicates an expected negative effect for industrial construction.

4.2 Adapted MPG calculation

Figure 2 provides the overview of the Production and Construction Phase of the MPG calculation according to the NMD and adapted, as applied in this study. A more detailed version is presented in Appendix A.

According to the NMD, there are five modules needed to calculate the environmental impact of houses. In this research, certain steps are added or distinguished:

- A1: extracting raw materials;
- A2: transport of raw materials to suppliers;
- A3.1: produce construction products;
- A4.1: transport of construction products directly to the construction site;
- A4.2*: transport of construction products to industrial construction firm;
- A3.2*: produce elements in the factory;
- A4.3*: transport of elements from factory to construction site;
- A5: Constructing at construction site.

**These steps are normally not mentioned in the official MPG calculation from the NMD*

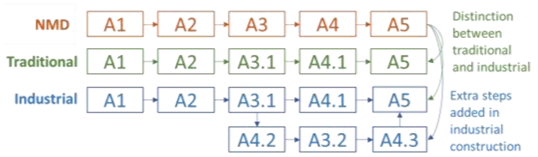

Figure 2 Module A of the MPG calculation according to the NMD and as applied in this study

4.3 Observations – Phase I

Based on the results from Phase I, certain observations were made.

First, the current MPG calculation does not distinguish traditional and industrial constructed houses due to not calculating the impact of the activities in the Construction Phase. The topics that require more precise calculation calculations are transport and machinery, construction waste and the construction of the housing factory.

Secondly, the main reason for the shift towards industrial construction is its speed and cost-effectiveness. Potential sustainable benefits are considered a bonus. In other words, sustainability needs to yield profit for the construction firms or should be mandated by the Dutch National government.

Lastly, due to certain issues with the MPG, several other concepts arise in the construction sector to prove sustainability. While the MPG was intended to fulfil the role of a unified method for calculating the environmental impact of houses, it has not been successful in doing so.

5. CASE STUDIES

To compare traditional and industrial construction, three case studies (A, B and C) were used, each consisting of two comparable scenarios (traditional and industrial).

It is important to note that the scenarios can be compared with each other, but the case studies cannot be compared.

Case A consists of a traditional and a comparable 3D industrial scenario and Cases B and C consist of a hybrid and a comparable 2D industrial scenario.

Hybrid construction is a combination of traditional and industrial construction, but for this study, it is classified as traditional construction.

6. MODELS

Five models were created to calculate the potential benefit of industrial construction, in CO_2 savings compared to traditional construction. These models calculated the following:

1. CO_2 emissions belonging to transport and machinery of Cases A and B;
2. CO_2 emissions belonging to transport and machinery of Case C;
3. CO_2 emissions belonging to construction waste in all cases;
4. CO_2 emissions belonging to the construction of the housing factory for all hybrid and industrial cases;
5. A model that adds on the aforementioned calculated CO_2 emissions to compare the construction methods and determine the potential benefit of industrial construction.

Various verification methods (e.g. extreme testing and comparing to real-life data) were used to verify the model.

7. RESULTS PHASE II: OVERVIEWS

This section provides the first part of the results of Phase II. In particular, the overviews of transport and machinery and construction waste in the Construction Phase of the MPG calculation for traditional and industrial construction.

The overviews are based on the conducted interviews and aim to provide a more detailed version of the activities in the Construction Phase and to visualise the differences between the construction methods.

The figures that present the overviews of transport and machinery are added in Appendix B and Appendix C. The difference between the construction methods when looking at these overviews is the extra steps needed in industrial construction. Those extra steps describe the transport movements to the housing factory (A4.2), from the housing factory to the construction site (A4.3) and the energy consumption needed in the housing factory (A3.2). Similar to both construction methods are the transport movement to the construction site

(A4.1) and the energy consumption needed on the construction site (A5).
The figures that present the overviews of construction waste are added in Appendix D and Appendix E. The differences between the construction methods when looking at these overviews are the extra possibilities to prevent waste, namely by suppliers, in the factory and on the construction site. Similar in both overviews, are the types of waste arising. The difference is that it is easier to separate waste in a factory compared to when constructing in urban areas since there might be a lack of space for waste containers in urban areas.

8. RESULTS PHASE II: POTENTIAL CO_2 SAVINGS

To determine the potential benefit of industrial construction in terms of CO_2 savings, three comparisons were made with traditional construction. This chapter presents the results of these three case studies.

8.1 Case A

Results of Case A (Table 1) indicate that a reduction of 49% of CO_2 emissions could be achieved for 3D industrial construction compared to traditional construction when focusing on transport and machinery, construction waste and the construction of the housing factory in the Construction Phase of the MPG calculation.
Appendix F presents more detailed results of Case A. A significant reduction in emissions was found in transport and machinery. This was primarily attributed to the reduction in time spent on the construction site.
There was also a strong reduction in emissions belonging to construction waste. This was primarily due to the calculation of the possibly avoided emissions. But also by the reduction in amounts of waste for industrial construction. This is due to the reasons described in Chapter 7.
The impact of the construction of the housing factory for traditional construction is zero since there is no housing factory included. For industrial construction, this was 0.96 $kgCO_2/m^2$bvo.
When adding all the calculated emissions belonging to transport and machinery, construction waste and the construction of the housing factory in the Construction Phase of the MPG calculation, the benefit of industrial construction is 38 $kgCO_2/m^2$bvo or a 49% reduction in CO_2 emissions per m^2bvo.

Table 1 Results Case A

	$kgCO_2$/scenario	$kgCO_2/m^2$bvo
Traditional	1,956	78
Industrial	997	40
Differences	959 (49%)	38 (49%)

8.2 Case B

Results of Case B (Table 2) indicate that a reduction of 33% of CO_2 emissions could be achieved for 2D industrial construction compared to hybrid construction when focusing on transport and machinery, construction waste and the construction of the housing factory in the Construction Phase of the MPG calculation.
Appendix G presents more detailed results of Case B. Different from Case A were the small differences in calculated CO_2 emissions belonging to transport and machinery between the construction methods (1 $kgCO_2/m^2$bvo in favour of industrial construction). A reason could be that hybrid and 2D industrial construction share more similarities compared to traditional and 3D industrial construction.
Similar to Case A is a strong reduction in emissions in Module A5 (on the construction site). In contrast, the emissions in Module A3.2 (production in housing factory) increase significantly. This can be explained by the fact that part of the construction process has moved from the construction site to the housing factory.
Also similar to Case A is the strong reduction in emissions belonging to construction waste. This was primarily due to the calculation of the possibly avoided emissions. But also by the reduction in amounts of waste for industrial construction. This is due to the reasons described in Chapter 7.
The impact of the construction of the housing factory is higher for industrial construction than for hybrid construction (a difference of 0.32 $kgCO_2/m^2$bvo in favour of traditional construction).
However, when adding all the calculated emissions of transport and machinery, construction waste and the construction of the housing factory in the Construction Phase of the MPG calculation, the benefit of industrial construction is 38 $kgCO_2/m^2$bvo or a 33% reduction in CO_2 emissions per m^2bvo.

Table 2 Results Case B

	$kgCO_2$/scenario	$kgCO_2/m^2$bvo
Traditional	8,051	57
Industrial	5,366	38
Differences	2,684 (33%)	38 (33%)

8.3 Case C

Results of Case C (Table 3) indicate that a reduction of 25% of CO_2 per m^2bvo emissions could be achieved for 2D industrial construction compared to hybrid construction when focusing on transport and machinery, construction waste and the construction of the housing factory in the Construction Phase of the MPG calculation.
Appendix H presents more detailed results of Case C. Similar to Case B were the small differences in calculated CO_2 emissions belonging to transport and machinery between the construction methods (2 $kgCO_2/m^2$bvo in favour of industrial construction).

A reason could be that hybrid and 2D industrial construction share more similarities compared to traditional and 3D industrial construction.
Different from Cases A and B is the high amount of CO_2 emissions arising in Module A4.1 This is due to the calculation of CO_2 emissions belonging to the transport of the machinery.
Similar to Cases A and B is a strong reduction in emissions in Module A5. In contrast, the emissions in Module A3.2 increase significantly. This can be explained by the fact that part of the construction process has moved from the construction site to the housing factory.
Also similar to Cases A and B is the strong reduction in emissions belonging to construction waste. This was primarily done to the calculation of the possibly avoided emissions. But also by the reduction in amounts of waste for industrial construction. This is due to the reasons described in Chapter 7.
The impact of the construction of the housing factory is higher for industrial construction than for hybrid construction (-0.19 $kgCO_2/m^2$bvo).
However, when adding all the calculated emissions of transport and machinery, construction waste and the construction of the housing factory in the Construction Phase of the MPG calculation, the benefit of industrial construction is 66 $kgCO_2/m^2$bvo or a 25% reduction in CO_2 emissions per m^2bvo.

Table 3 Results Case C

	$kgCO_2$/scenario	$kgCO_2/m^2$bvo
Traditional	14,330	87
Industrial	9,502	66
Differences	4,828 (34%)	21 (25%)

8.4 Observations - Phase II

Based on the results from Phase II, certain observations were made.
First, in the Production Phase of the MPG, the environmental impact is calculated on product level, while the Construction Phase is on project level. Since every project is unique, it is hard to establish Environmental Profiles suitable for every project. Therefore, the impact of activities in the Construction Phase is often not calculated.
Secondly, the environmental impact of the Production Phase is greater than that of the Construction Phase, implying that the choice of material may have a greater impact than the construction method.
Lastly, the current MPG calculation is not accurate enough to determine the environmental effect of industrial construction. The currently uncalculated topics already result in a difference of 25-49% CO_2 emissions per m^2bvo.

9. DISCUSSION

It is difficult to compare traditional and industrial construction, as each construction project is unique. The construction firms provided calculated data for transport and machinery (Cases A and B), ensuring reliability. However, for Case C, assumptions were necessary due to limited data, rendering its results less reliable.
The study challenges the perception that constructing a housing factory has a greater impact than reducing transport, machinery, and construction waste. Instead, results show that transport and machinery have the most significant impact, possibly due to the focus on the Construction Phase of the MPG calculation or the limited data available on the housing factories.
Interviews with sustainability experts and work planners inform recommendations for stakeholders, acknowledging limited participant diversity. Limitations include uncertainties in life cycle assessments (LCAs), companies' reluctance to share confidential data, and the study's focus solely on the Construction Phase of the MPG calculation.

10. CONCLUSION

This section aims to describe the conclusions that can be drawn based on the results of Phase I and Phase II.
The currently insufficiently reflected topics that in theory influence the MPG and could result in a different environmental impact for traditional and industrial construction are:

- The impact of transport and machinery (+);
- The impact of construction waste (+);
- The impact of constructing a housing factory (-).

Other conclusions that can be drawn based on the results of Phase I are:

- The current MPG calculation does not distinguish traditional and industrial constructed houses;
- The main reason for the shift towards industrial construction is its speed and cost-effectiveness;
- While the MPG was intended to fulfil the role of a unified method for calculating the environmental impact of a house, it was not successful in doing so.

Another result of Phase I is the adapted MPG calculation (Figure 2). This adapted method and the currently insufficiently reflected topics (transport and machinery, construction waste and the construction of the housing factory) were used in Phase II to determine the potential benefit of industrial construction in the Construction Phase.
The benefit of industrial construction in the Construction Phase of the MPG calculation for the aforementioned topics is a reduction of 25-53% in $kgCO_2$ per m^2bvo (or 21-38 $kgCO_2/m^2$bvo). This is dependent on the construction method of the scenarios. The differences in CO_2 emissions between traditional and 3D industrial construction are larger

than the differences between hybrid and 2D industrial construction.

Other conclusions that can be drawn based on the results of Phase II are:

- The Production Phase calculates the impact on product level, while the Construction Phase calculates the impact on project level. Since every project is unique, the impact of the activities in the Construction Phase is often not calculated in the Environmental Profiles;
- The emitted CO_2 emissions in the Production Phase are larger compared to the emissions coming in the Construction Phase. In other words, other materials may affect the environmental impact more than another construction method;
- The current MPG calculation is not accurate enough to calculate and compare the environmental impact of construction methods.

11. RECOMMENDATIONS

This section provides recommendations for key stakeholders in industrial construction, which are: industrial construction firms, the government, the NMD, clients and suppliers. A full table with barriers, recommendations and opportunities is added in Appendix I.

The primary obstacle to reducing the environmental impact of industrial construction is the current economic system [7]. Currently, either requiring a lower environmental impact or making a profit by lowering the environmental impact would help reduce the environmental impact in the construction sector. Other barriers include among others technical development and the lack of regulations [7].

To reduce the environmental impact of industrial construction, recommendations include enforcing stricter regulations for sustainable construction, monitoring the MPG regulations, improving communication, providing more accurate Environmental Profiles, exploring alternatives to diesel trucks and investing in sustainable materials*. Industrial construction firms could choose alternatives for diesel trucks, implement sustainable materials*, implement renewable energy sources and further optimise waste management [7].

**materials with a reduced environmental impact compared to their traditional alternative, for example, biobased or secondary materials.*

12. FURTHER RESEARCH

Recommendations for further research include adapting the MPG calculation for industrial construction, exploring a tipping point where hybrid construction's environmental impact might be lower than industrial construction's environmental impact and establishing monitoring mechanisms to ensure built structures align with calculated MPG scores.

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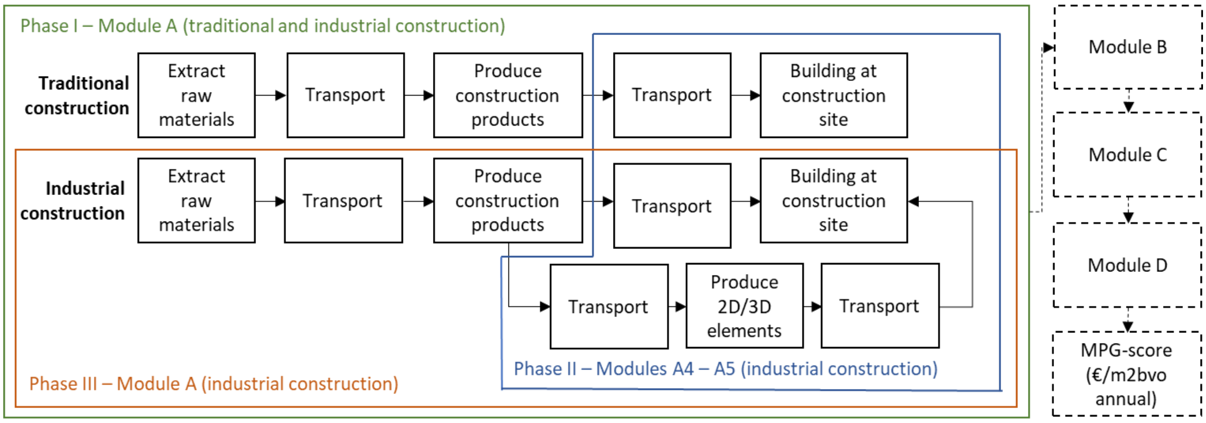
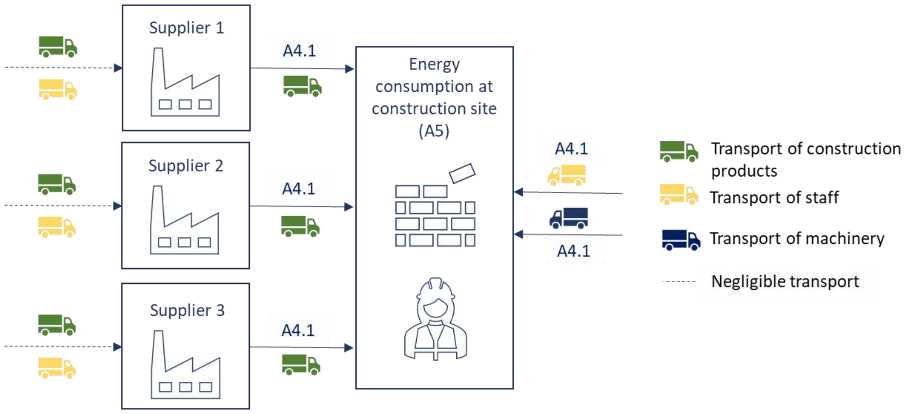
Appendix A

System boundaries



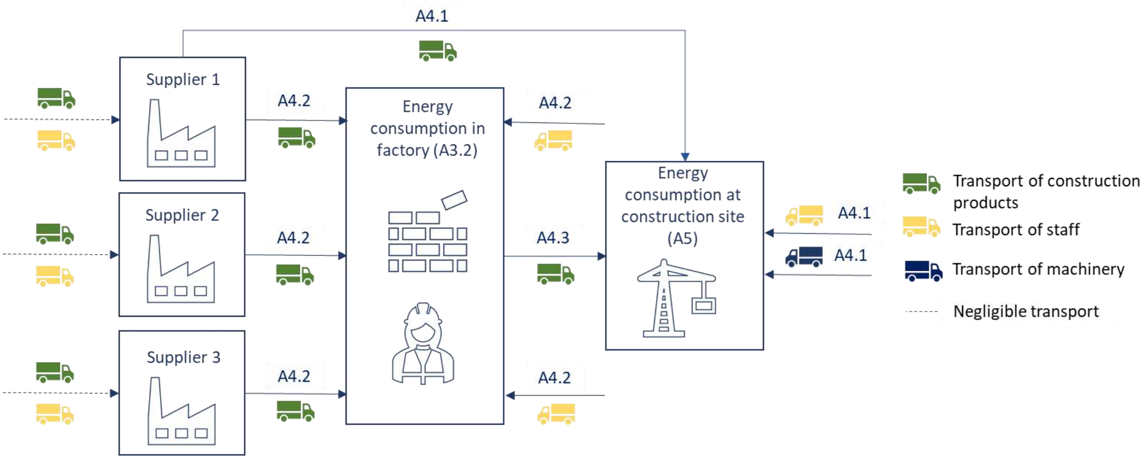
Appendix B

Overview of transport and machinery for traditional construction



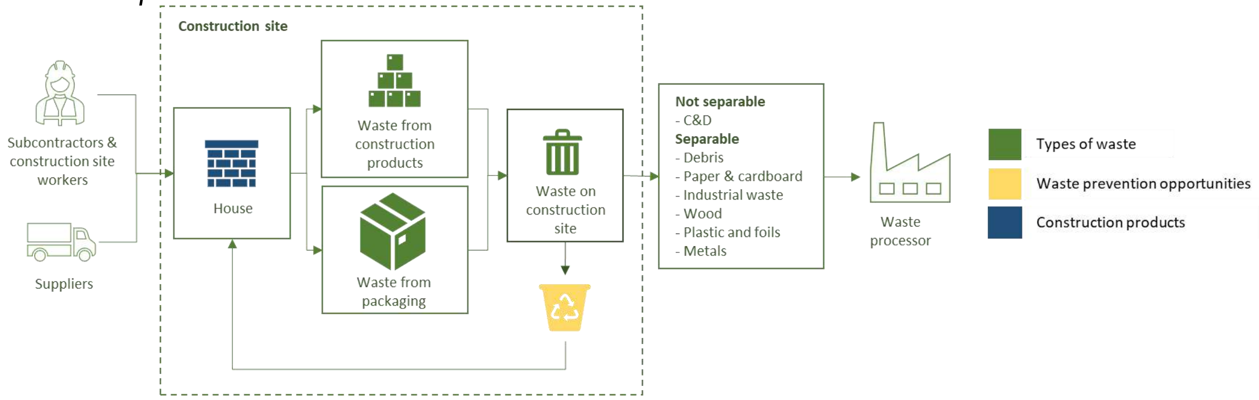
Appendix C

Overview of transport and machinery for industrial construction



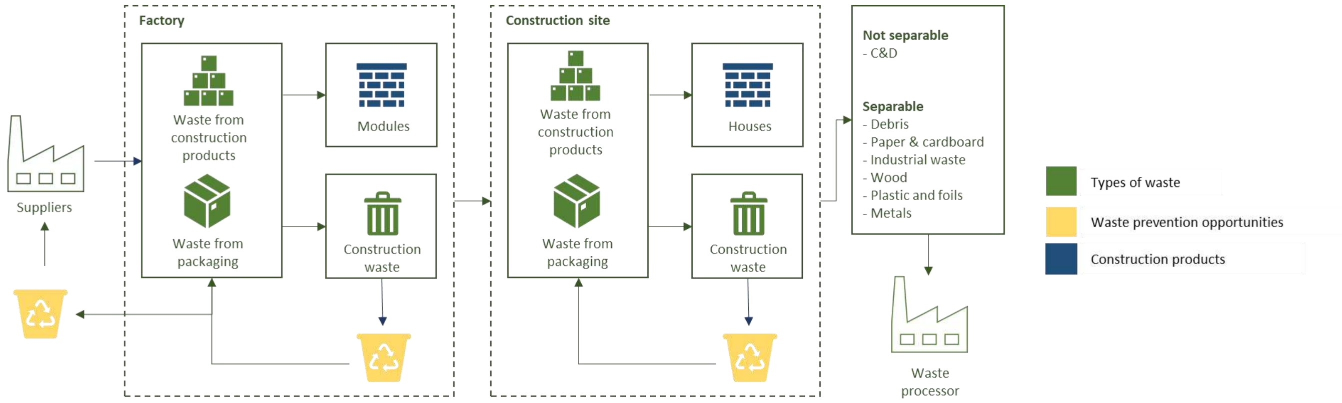
Appendix D

Overview of construction waste in traditional construction



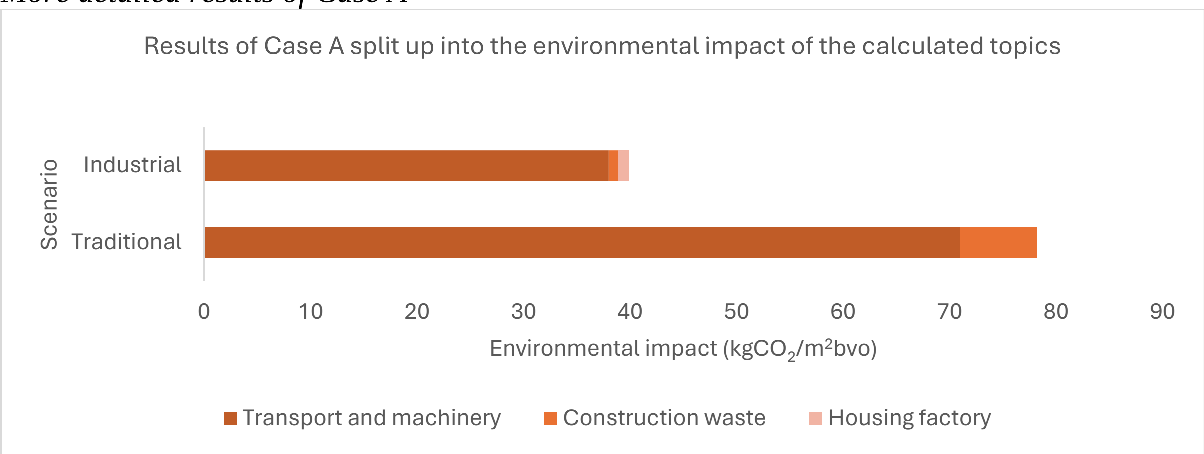
Appendix E

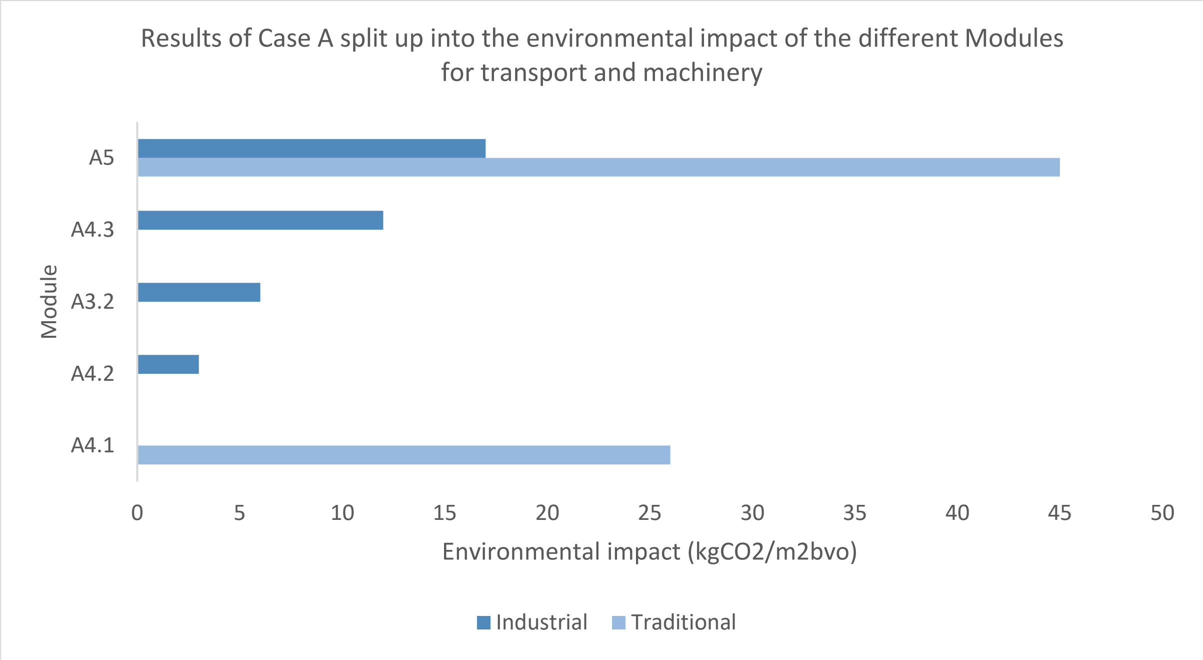
Overview of construction waste in industrial construction

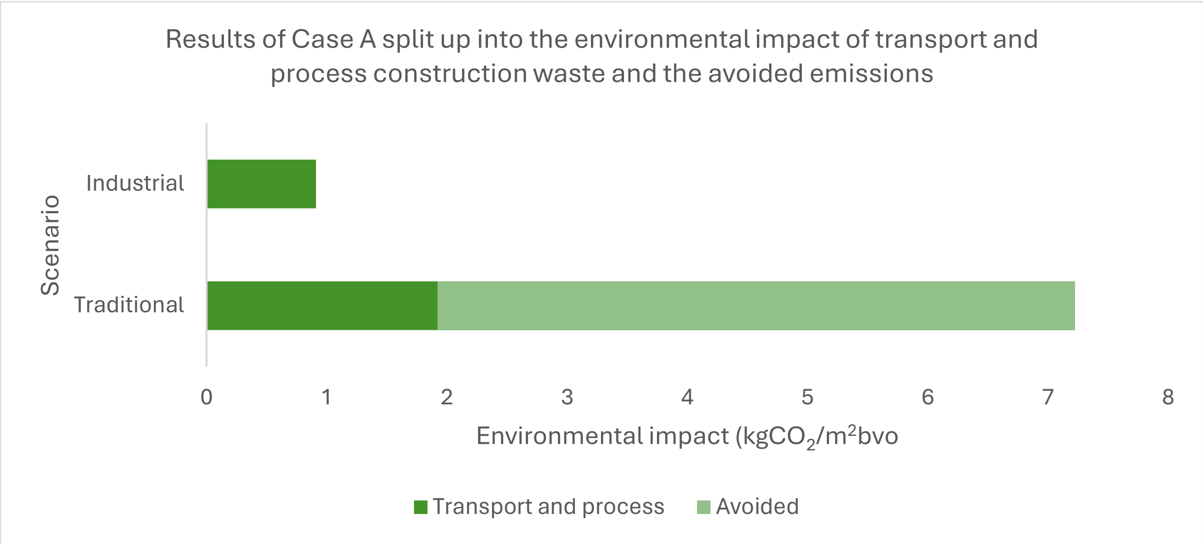


Appendix F

More detailed results of Case A

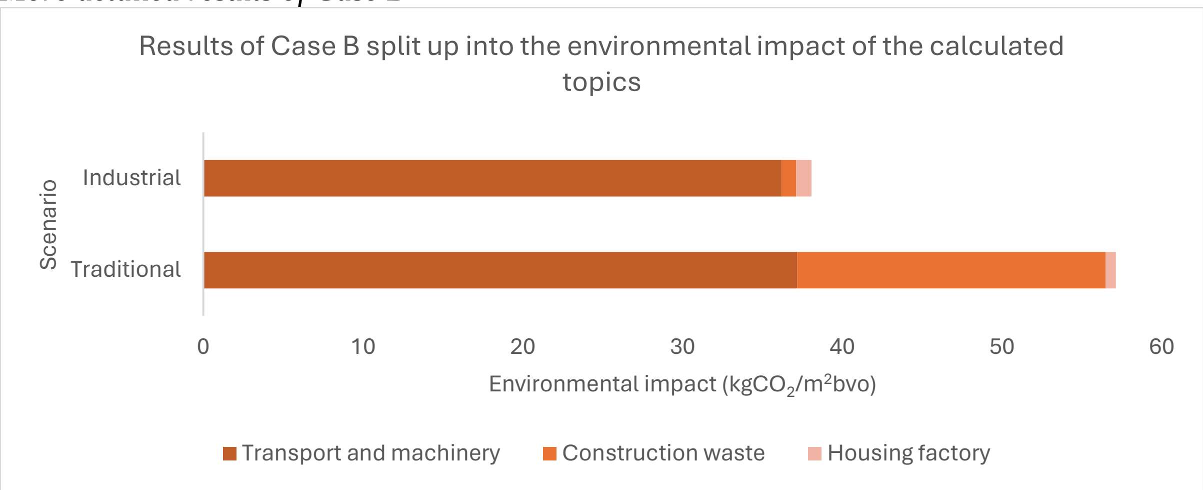


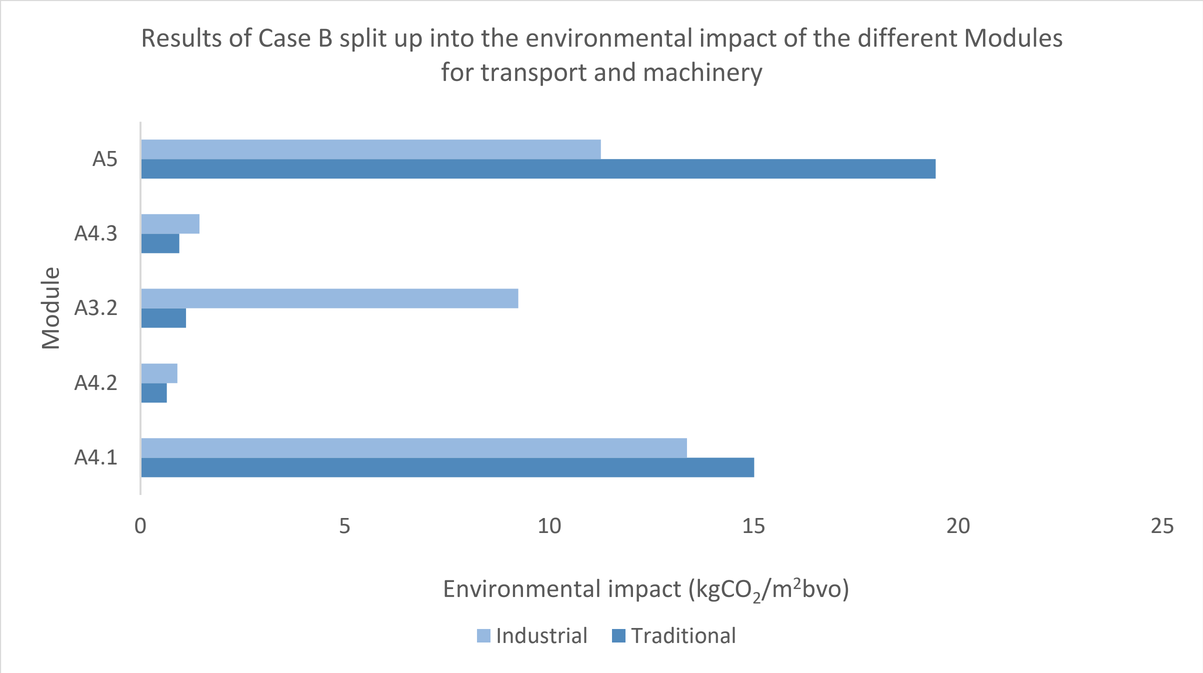


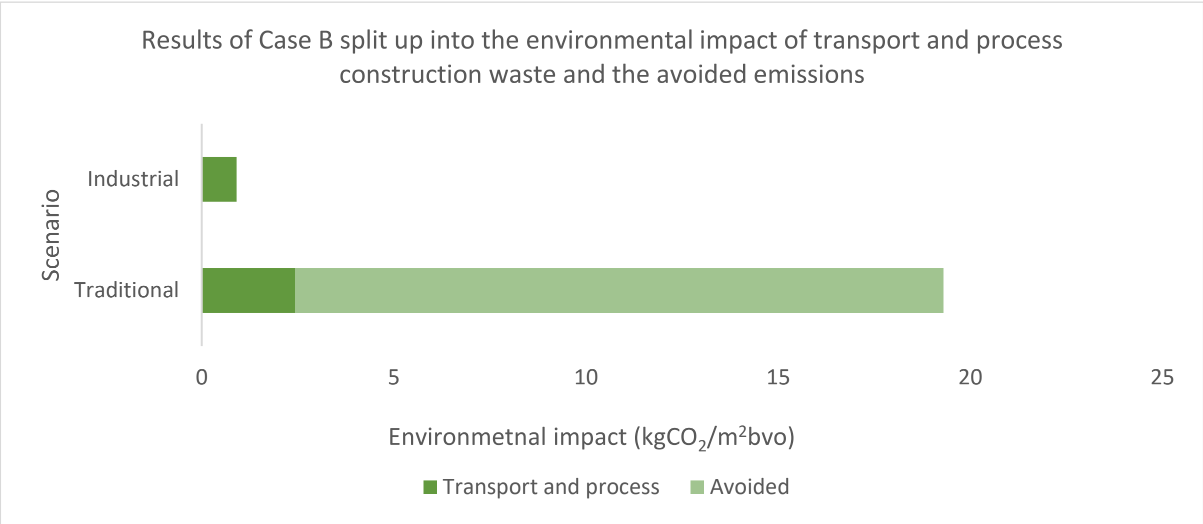


Appendix G

More detailed results of Case B

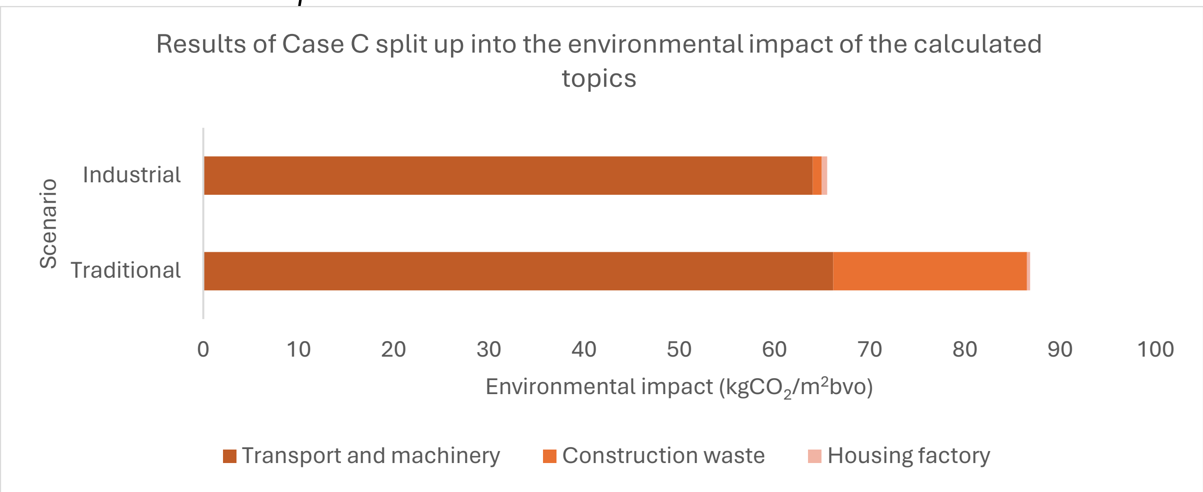


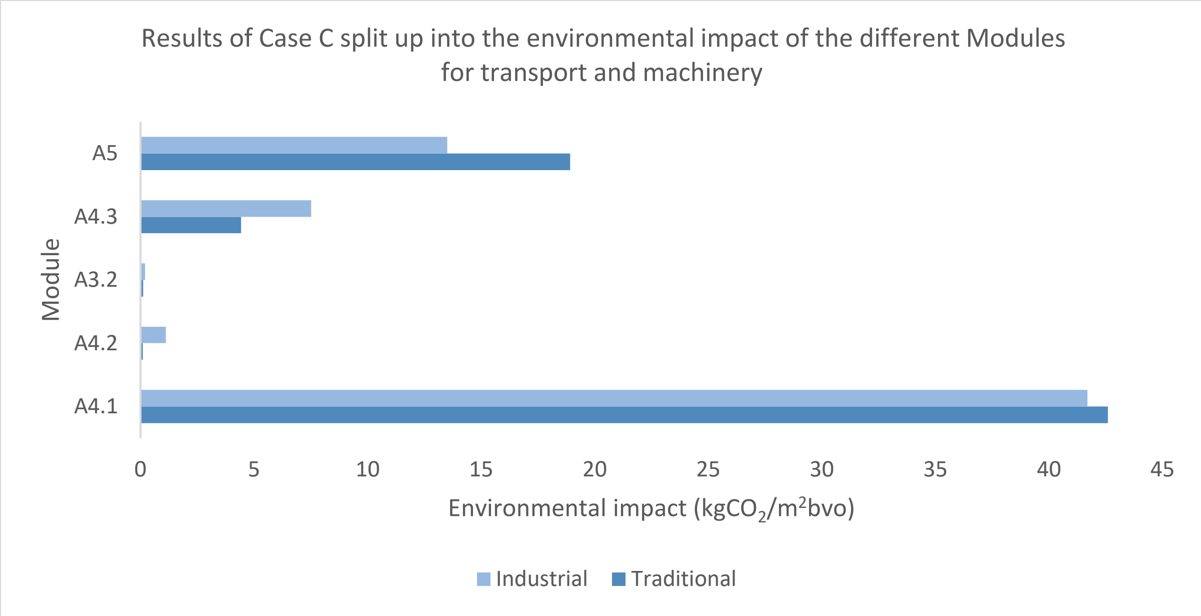


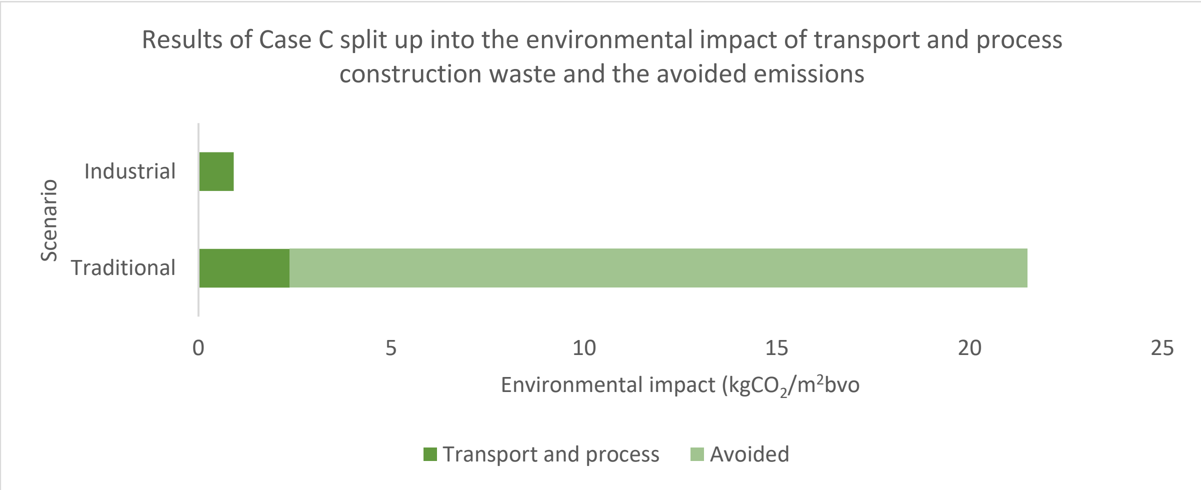


Appendix H

More detailed results of Case C




Results of Case C split up into the environmental impact of the different Modules for transport and machinery
Module
A5
A4.3
A3.2
A4.2
A4.1
0
5
10
15
20
25
30
35
40
45
Environmental impact (kgCO2/m2bvo)
Industrial
Traditional


Results of Case C split up into the environmental impact of transport and process construction waste and the avoided emissions
Scenario
Industrial
Traditional
0
5
10
15
20
25
Environmental impact (kgCO2/m2bvo)
Transport and process
Avoided

Appendix I

Recommendations for stakeholders

Barrier	Recommendation	Stakeholders
The need for more regulations from the government	The national government should require stricter regulations around sustainability of residential buildings that stimulate construction firms in reducing the environmental impact of industrial construction.	National government
No monitoring of the MPG regulations	The regional government should monitor whether the delivered MPG is actually built; Construction firms should be more transparent about their MPG calculation and the final constructed house.	Regional government & industrial construction firms
Data-quality NMD could be better	Improve the MPG calculation for industrial constructed residential buildings by for example implementing the topics calculated in this study*; Industrial construction firms should establish LCAs in order to produce more accurate Environmental Profiles of their produces elements.	The NMD & industrial construction firms
Communication from the NMD could be better	The NMD should communicate in advance before deleting environmental profiles. This will allow construction firms to prepare themselves and prevent sudden reductions in the MPG.	The NMD
The fact that innovation is there, but not implemented yet	Clients should invest in projects that use sustainable materials and challenge construction firms to reduce the environmental impact of the houses they build; Industrial construction firms should invest the money saved in sustainable materials**; Suppliers should offer a variety of sustainable materials**, whenever possible with guarantees.	Clients, industrial construction firms and suppliers

**The downside of this recommendation, is that this study researched the topics that are currently perceived to be insufficiently reflected in the MPG. A risk arises that when calculating these topics in an LCA, the environmental profiles will be higher than the traditional alternative. Unless the traditional alternative also calculates these topics.*

***Sustainable materials are materials with a reduced environmental impact compared to their traditional alternative (e.g. biobased or secondary materials).*