# Tiny House Movement and LCA of Tiny Houses in the Netherlands

## Case Study of Tiny Houses in the Netherlands

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**Abstract** *Purpose* The main objective of this report is to describe the Tiny House Movement in the Netherlands and to examine the impact on the global warming of construction and insulation materials which are used for a tiny house. The assessment might support new tiny house owners in their material choice.
*Methods* This study consists of a life cycle assessment, cradle-to-gate, of three tiny houses: one built with only new materials (Case A), one built with only reclaimed materials (Case B) and one tiny house built with new and reclaimed materials (Case C). The cradle-to-gate phase enclose the raw material extraction, manufacture construction and insulation materials, transport of the raw materials to the manufacture, transport from the shop to the building site, transport from the building site to the living site and the electricity use for the used tools. The calculations of the life cycle assessment are done with the GaBi Education Software in combination with the GaBi ecoinvent Database and literature. The functional unit is formulated as $kg\ CO_2/m^2$, for a lifespan of 50 years.
*Results and Discussion* Sheep Wool has the highest impact on the global warming potential per squared meter. And the results show that the transport has a low environmental impact in comparison with manufacturing of the materials. The use of products coming from animals is open to question, in this study the Sheep Wool is considered as main product and not as byproduct which results in a higher environmental impact of the Sheep Wool.
*Conclusions* Buying materials not far away is more environment friendly. This study also showed that assumed byproducts needs a second thought: "Are the materials actually a byproduct in the manufacturing process or are they main products nowadays"?

**Keywords** LCA · Tiny House · Cradle-to-gate · Insulation materials · Construction materials · Tiny House Movement · $CO_2$-emission

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## 1 Introduction

In the late '80, the United Nations World Commission on Environment and Development have defined sustainability as: *"development that meets the needs of the present without compromising the ability of future generations to meet their own needs"* [1]. Sustainability considers the balance between the three pillars of sustainability; economic development, social development

and environmental protection. The United Nation set seventeen goals to meet the sustainable needs for resolving the social, economic and environmental problems in the world [2], the Sustainable Development Goal (SDG). This attention to the consequences of global warming led to more awareness and made sustainability an important topic at the agenda.
The SDGs functions as a guide for over the next 15 years on sustainable development activities. According to the American Society of Civil Engineer: *"Engineers shall hold paramount the safety, health and welfare of the public and shall strive to comply with the principles of sustainable development in the performance of their professional duties"* [3]. All of the SDGs provide challenges for the work of civil engineers. This report is focusing on the environmental global warming potential of the building sector.
The European Union states that the energy consumption of buildings is responsible for 40% and a $CO_2$-emission of 36% in the EU and therefore the building sector is the largest energy consumer in the EU [4]. In The Netherlands the Dutch building sector is responsible for 40% of the energy consumption, 35% of the $CO_2$-emission and 50% of all raw material use is coming from the building sector [5].
The government of the Netherlands is aware of their contribution to the $CO_2$-emission and introduced a new legislation which came into act in January 2018: the environmental impact of the materials, MPG (in Dutch: Mileubelasting van materialen). The MPG is based on the lice cycle costs of the building and has a maximum value of 1 /m$^2$. [6][7]. In the life cycle costs the initial costs and the disposal costs needs to be considered. Where initial cost covers the costs of the processes in the cradle-to-gate phase. [8] Which means in governmental terms, lower values of the MPG concludes more use of sustainable materials [6].The MPG is only required for new buildings with a floor area of more than 100 m$^2$ [6]. Due to the MPG a beginning of the $CO_2$-reduction in the production of materials is started. Since 2018, the Dutch government uses laws for the amount of $CO_2$ in construction materials [9] to provide circularity in raw materials and their products. In 2016, the Netherlands 44% of the homes are smaller than 100 m$^2$ [10]. This means the MPG would have been applicable to 56% of all the houses in the Netherlands.

## 1.1 Average living area in the Netherlands

Since 2015 the average living area of a house in the Netherlands is 114m$^2$, this is a decrease from 2005-2015 and equal to the 90s [11]. As shown in Figure1, the fastest growth of number of houses is for living areas below 75 m$^2$ in the last four years [10]. The mean living area in a single-family dwelling for private property is 140 m$^2$ and for rented accommodation 89 m$^2$ [12] with a mean of 106 m$^2$ [13].
Housing corporations are developing smaller houses over the years [14].In 2017, 10% less residences with an average living area of 100-150 m$^2$ were developed in comparison with 2014 [13]. The decrease in average living area could be declared by housing development that is more targeted to limited budget and the life phases [13][14].
The decrease of average living area is also related to the change of household size and composition: more single parents, more independent seniors [15] and the decrease of household size [16]. Another reason is the grown group of interested people that actually prefer to live in smaller houses. In general, there are two types of small houses: micro-homes and tiny houses. Both of those groups live in a house which is not larger than 40 m$^2$.
The differences between the houses are the house type and the location. Micro homes are mostly built in urban areas and the residents of a micro home are mostly working in the surrounding area. Instead, tiny houses contains a different kind of lifestyle. A life with financial freedom (living mortgage free), less ecological footprint and living with a congenial group. [17] Since 2009, the amount of people living in small houses is increasing till 40m$^2$ and between 40m$^2$ and 60m$^2$ respectively from 1.5% to 4.0% and 2.5% to 5.0% [17].

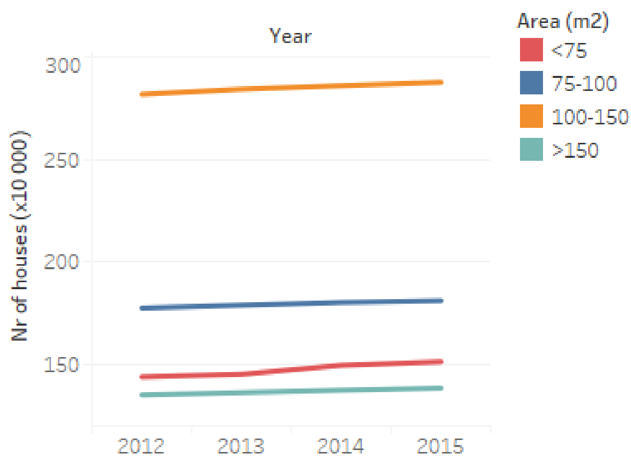


**Fig. 1** Housing stock in the Netherlands 2012-2015 (data gained from [10])

## 1.2 Definition of a Tiny House

Tiny houses have a sustainable reputation [18]. For the SDGs and the climate change tiny houses do have a potential. A selection of tiny houses are off the grid an may be self supporting. The last fact is important because of the goals of being $CO_2$-neutral in 2050 for all houses and for 2020 for new buildings in the Netherlands [19]. Unfortunately, there is a lack of academic papers about tiny houses and a consistent definition of a tiny house. Ryan Mitchell does not focus on the dimensions and technical aspacts of a tiny house but more on the social aspects. Mitchell is focussing on the following three pilars: *"*

- *It focuses on effective use of space*
- *It relies on good design to meet the needs of the residents*
- *It serves as a vehicle to a lifestyle that the resident wishes to pursue". [20]*

Marjolein Jonkers, the first person who is living in a tiny house in the Netherlands [21] [22] focus besides the social aspects also on the design, surface area and support material choice with a smaller ecological footprint. *"Tiny Houses are primary, full-fledged dwelling ... With less focus on material possessions and with a smaller eco footprint ... A Tiny House is up to 50 m2 ... Being mobile and/or fully off-grid is a possibility, not a requirement"*[23].

Remmelink describes a tiny house as *"A tiny house is a fully equipped house, with an area that does not exceed 28 m2. A tiny house has been built in a sustainable manner and is meant to be occupied all year round"* [24]. Remmelink names surface area and building sustainable. But he do not argues the mobility of a tiny house.
Those three definitions form the basic of the definition which will be used in this report. The definition set for this report is more strict and measurable than the first two definitions and it is more complete than the last one. The definition which will be used in this report is as follows:
*"A tiny house is a structure that provides everything you need to live with the focus on a smaller ecological footprint, being mobile, off-grid and a maximum ground surface of 30 m$^2$ and a maximum weight of 3500 kg including the trailer."*
The area of 30 m$^2$ and the weight of the tiny house is established due to the maximum dimensions and weight of a trailer in the Netherlands. The maximum width is 2.55m, the maximum length is 12m and the maximum weight of trailer behind a car is 3500 kg. [25]

## 1.3 Tiny House Movement in the Netherlands

The costs of tiny houses are much lower than the cost of a real dwelling. In The Netherlands the sales price of an average single-family dwelling is 292,000 euros [26] and the average surface of a single-family dwelling is 143 m$^2$ [11]. So, the average price per square meter is 2042 euros. In comparison to a tiny house with a ground surface of 30 m$^2$ and the average cost of 40,000 euros [27][28], the price per squared meter tiny house is 1333 euro, taken into account that most of the tiny houses also have a storey, the cost per square meter will be lower. The 27% lower housing price is not the only advantage. Mortgage free life results in less distress. On top of that, a lower amount of needed building materials might lead to a lower carbon footprint.
Besides the advantages there also are disadvantages. The greatest obstacle is to find a place to live. In the United States most of the tiny houses are built on a trailer to bypass the rules [24]. Fulfil the requirements set by the governments about safety and dimension is hard to tackle. And the interest of living in smaller houses is growing faster than the government can adapt new rules and change the Building Codes for a dwelling. The growing interest to live smaller, to live more sustainable and the lack in Building Codes bring people with this same mind together. This group is named the Tiny House Movement. Living smaller and environmentally friendly originally started in the North America in the late 90s, and after the housing market crashed this group grow faster. Later on it moved to Europe. [29]
Marjolein is the ambassador of the Tiny House Movement in The Netherlands with the following mission: "make the Netherlands familiar with the philosophy behind the movement and to enable living legally in sustainable tiny houses in more places" [30].

On May 2016, the Tiny House Movement contains 26 places in 26 municipalities where groups are active to realize a tiny house [31] and on November 2018 the amount of places is grown to 167 in 143 municipalities [32]. In November 2018 there are 59 places where tiny houses are built, this is almost six times more than in May 2016. In 2.5 years, the interest increased with almost 7 times. The people with interest are forming groups to start an initiative. With a collaboration of the municipalities and advice from people who already live in a tiny house, the initiatives try to come to an agreement with municipalities to get a place to live and to make use of more lenient Building Codes.

Living in a smaller house needs less construction materials and results in a decrease in carbon footprint [33].

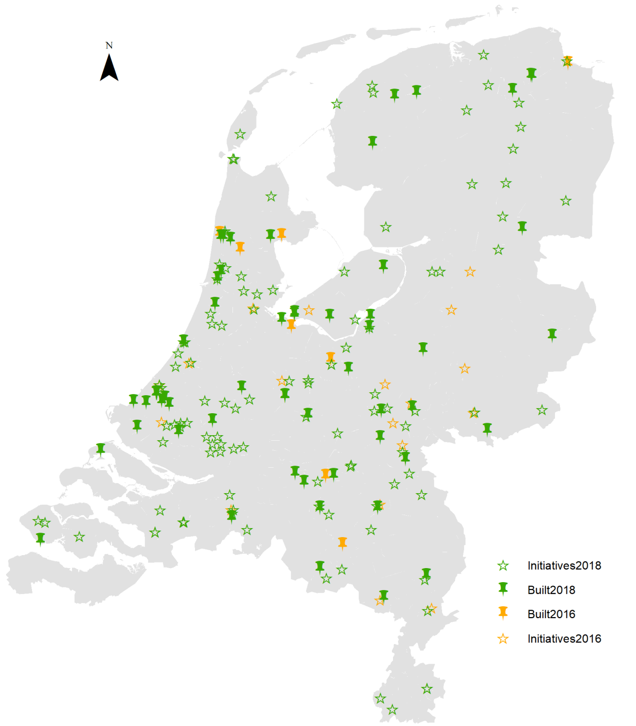


**Fig. 2** Progress May 2016-November2018 (data gained from [31][32])

Academic articles about life cycle assessment (LCA) of dwellings are existing but not about the LCA of a tiny house. The LCA is an important instrument to shape environmental policy because the LCA provides insight into environmental effects. This way you get information about in which phases which effects occur and you can compare products/materials with each other based on their environmental effects.
This study looks at the LCA, from cradle-to-gate, of tiny house construction and insulation materials in three types of tiny houses to identify their contribution to the greenhouse gases.
Finally, this report provides the University of Twente with an advice of building materials in the Twente Region to built on their campus on a sustainable manner.

## 2 Case Study

The study is focussing on tiny houses in The Netherlands. The cradle-to-gate variant of the LCA is used to calculate the environmental effects of the construction and insulation materials. The cradle-to-gate measures the environmental effects of the extraction (cradle) to the factory gate. In this study the following is included the electricity for the construction of a tiny house, the transport of the materials from the shop to the building site and the transport of the building site to the final location of the tiny house are included. The distance from the factory gate to the shop is neglected.
The environmental effect of three different types of tiny houses located in the Netherlands are calculated.

**Table 1** Basic Characteristics of the Case Study Tiny Houses

| Case | Dimensions (LxWxH) [m] | Width Floor[1] [m] | Width Roof[1] [m] | Width Wall[1] [m] |
|---|---|---|---|---|
| A | 6.60x2.55x4.00 | 0.18 | 0.12 | 0.13 |
| B | 6.55x2.55x3.80 | 0.35 | 0.10 | 0.27 |
| C | 8.70x3.00x3.78 | 0.11 | 0.15 | 0.11 |

**Case A** Tiny house built with only new materials
**Case B** Tiny house built with only reclaimed materials
**Case C** Tiny house built with new and reclaimed materials

The reclaimed materials are second hand materials which are bought from non commercial private persons. The new materials refer to materials bought in a shop or online shop.
The basic characteristics of the tiny houses which will be analyzed in this report are shown in Table1. This information is gathered from Dutch citizens who are living in a tiny house. Those people were also interested in their footprint of their cradle-to-gate phase and were willing to share their construction information for this research. Case A is designed by an architect who believes in compact and efficient living to increase happiness and reduce the ecological footprint and Case A is built by a carpenter. Case B and Case C are both built and designed by the residents. Case A is situated in the province of North Holland, Case B in the province of Gelderland and Case C is located in North Brabant.

## 3 Materials and Methods

This study is focusing on the construction and insulation materials which are used in the floor, walls and the roof of a tiny house. The tiny houses are placed in one of the three categories, see Section 2, to get more insights in the differences in contribution to the greenhouse gases of the cradle-to-gate phase.
The LCA methodology is used as a tool to quantify and compare the greenhouse gases of the construction and insulation materials of several tiny houses in The Netherlands. The LCA consist of four phases; (1) Goal and Scope Definition, (2) Lifecycle Inventory, (3) Impact Assessment and (4) Interpretation. Those four steps will be expound in more detail.

[1] Excluding gaps

3.1 Goal and Scope Definition

This report *aims* to establish a comparative LCA of the construction and insulation materials which are used for a tiny house, which emphasized the effect to the environmental impact and notwithstanding the effect of the transport distances. Not all the tiny houses are built at the final living location. Figure 3 shows the transport of the materials to the final destination, place D where the tiny house will stay for several years. The *system boundary* to calculate and compare the environmental impact of the construction and insulation materials concludes the process of cradle-to-gate as shown in Figure 3. The lifespan of the tiny houses is set to 50 years because this is the lifespan the three residents aspect. Due to time limitations and data availability not the whole LCA, cradle-to-cradle, is executed.
In this study the environmental impact of the floor, walls and roof will be studied and therefore the *functional unit* of 1 $m^2$ floor/wall/roof will be used as indicator for the global warming potential.

3.2 Lifecycle Inventory

The lifecycle inventory (LCI) is about data collection and calculation procedures [34][35]. Those people have shared their constructions including material use, distance A and C of Figure 3 and they indicated if the material was reclaimed or newly bought. An overview of this information is shown in Table 2. The GaBi Education Software is used for calculations. The respondents did not know where the materials were extracted. Therefore the GaBi ecoinvent Database is used, see section E of Figure 3. The GaBi Education package could not provide the processes of Flax insulation and sheep wool insulation. These information is gathered from only literature. The literature did not make a distinction between transport and the manufacturing (including extraction).

A couple assumptions are made because of a lack on information:

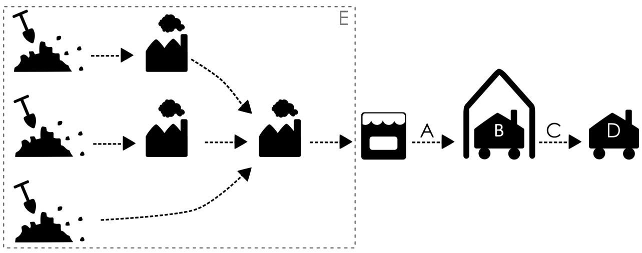


**Fig. 3** System Process

– For Case C the missing distance A is set to 15 km
– Electricity for shops and the building place, hot water and heating the building place is neglected
– Electricity for tools is assumed and based on Case A. It takes three weeks to build the outskirt of a tiny house according to D. Wentzel. Assumed 800 Watt for sawing and 700 Watt for drilling.
  * Wall: 0.27 kWh/$m^2$ based on 24 hours sawing and 1 hour drilling
  * Roof: 0.82 kWh/$m^2$ based on 16 hours sawing and 1.5 hour drilling
  * Floor: 0.11 kWh/$m^2$ based on 1 hours sawing and 1.5 hour drilling
– Windows and doors are neglected
– There is no difference made between reclaimed and new materials in the analysis

3.3 Impact Assessment

The lifecycle impact assessment (LCIA) is a translation of the output of the LCI. The output can be translated into two approaches: (1) problem-orientated mid-points approach and (2) the damage-orientated end-point approach. The first one is a translation of the environmental impacts to midpoint categories like global warming, ozone layer depletion, human toxicity and for example mineral extraction. The second approach translates the first approach to the damage to human beings, environment, climate change and resources. [36]. To make the calculations for the global warming, approach one, the impact assessment CML2001 is chosen. This is done because the normalisation factors are available for the Netherlands. In this analysis only the global warming potential (kg $CO_2$-eq) is considered.

3.4 Interpretation

The interpretation is the connection between the LCI and the LCIA to come to a conclusion, decision-making and recommendations in accordance with the goal and scope of definition of this study. The $CO_2$-emission is chosen to compare the three case studies because this is one of the main pillars to adapt the climate change.

## 4 Results

Results for the $CO_2$-eq produced by the production and transport of the construction and insulation materials are shown in Figure 4 for each type of material per

[2] Reclaimed material

case study. In all cases, the contribution of transport and electricity is relatively low in comparison to the other categories. Figure 5 shows the $CO_2$-emission per suqared meter produced by the production and transport of the construction and insulation materials except for the electricity use of the tools to build the tiny house.

The roof and floor of Case A and Case B have the same area, respectively 16.83 $m^2$ and 16.70 $m^2$. In Case C, the roof has a larger area than the floor, respectively 28.08 $m^2$ and 24.54 $m^2$. Striking is the visualisation, in Figure 4, of the impact of the insulation material of Case A in the wall, sheep wool. Compared with the functional unit, shown in Figure 5, the impact of the sheep wool is the same as for the roof and floor of Case A per squared meter.

Table 3 shows the $CO_2$-emission per functional unit (kg $CO_2$-e/$m^2$). Case A has the highest values of all the three cases for the production and the transport per functional unit. Based on these results the tiny house of Case A has the most negative impact on the climate change in their production phase for the total house and per functional unit.

Case A is the only tiny house built with especially new materials. Despite the assumption to neglect the change in $CO_2$-emission for the reclaimed materials of Case B and C and calculate with the reclaimed materials as they were new, Case A still has the most negative impact on the global warming.

When materials are applied multiple times within or among the cases, the same source of literature or database is used. For example, the beams used for the floor for Case A and for the Wall of Case B have the same input variables except for the transport distance and the amount of materials. And therefore the $CO_2$-emission per kilogram of material of the production process is the

**Table 2** Input of the LCA

| | Section of house | Material | Type of material | Mass (kg) | Volume ($m^3$) | Transport distance A (km) | Transport distance C (km) |
|---|---|---|---|---|---|---|---|
| Case A | | | | | | | |
| | Floor | Beams | Construction | 689.02 | 1.5 | 59.67 | 160 |
| | | Ecoboard | Construction | 196.91 | 0.3 | 293 | 160 |
| | | Concrete plex | Construction | 33.66 | 0.07 | 59.67 | 160 |
| | | Sheep Wool | Insulation | 20.9 | 1.16 | 220 | 160 |
| | Roof | Celit | Construction | 99.97 | 0.37 | 220 | 160 |
| | | Planks | Construction | 139.35 | 0.3 | 212 | 160 |
| | | Plywood | Construction | 83.31 | 0.15 | 59.67 | 160 |
| | | Sheep Wool | Insulation | 20.9 | 1.16 | 220 | 160 |
| | Wall | Celit | Construction | 434.81 | 1.61 | 220 | 160 |
| | | Planks | Construction | 606.1 | 1.32 | 212 | 160 |
| | | Ecoboard | Construction | 523.38 | 0.81 | 293 | 160 |
| | | Sheep Wool | Insulation | 90.91 | 5.05 | 220 | 160 |
| Case B | | | | | | | |
| | Floor | Plywood[2] | Construction | 165.35 | 0.3 | 12 | 0 |
| | | Glass wool[2] | Insulation | 53.45 | 2.67 | 4.2 | 0 |
| | | Rock wool[2] | Insulation | 85.52 | 2.67 | 4.2 | 0 |
| | Roof | Sandwich panels[2] | Insulation and Construction | 33.41 | 0.84 | 33 | 0 |
| | | Sandwich panels[2] | Insulation and Construction | 33.41 | 0.84 | 33 | 0 |
| | Wall | Beams[2] | Construction | 1611.96 | 3.5 | 262 | 0 |
| | | Planks[2] | Construction | 644.78 | 1.4 | 260.6 | 0 |
| | | Rock wool[2] | Insulation | 224.27 | 7.01 | 4.2 | 0 |
| | | Sandwich panels[2] | Insulation and Construction | 280.34 | 7.01 | 260.6 | 0 |
| Case C | | | | | | | |
| | Floor | Concrete plex | Construction | 184.05 | 0.37 | 15 | 5 |
| | | PIR[2] | Insulation | 66.9 | 2.31 | 50 | 5 |
| | Roof | Gypsum | Construction | 2.67 | 0.27 | 15 | 5 |
| | | PIR[2] | Insulation | 117.26 | 4.04 | 50 | 5 |
| | Wall | Spruce | Construction | 589.42 | 1.28 | 16 | 5 |
| | | Gypsum | Construction | 8.9 | 0.89 | 15 | 5 |
| | | OSB-3 | Construction | 469.83 | 0.78 | 16 | 5 |
| | | Flax Insulation | Insulation | 149.49 | 4.98 | 40 | 5 |

same. For example, the beams of Case A and Case B do not have the same amount of kg $CO_2/m^2$ because of the difference in thickness in material. The $CO_2$-emission for each material per squared meter per Case is shown in Table 4.
The $CO_2$-emission of the Sheep Wool has, compared to other insulation materials, the most negative impact on the global warming per Case and per squared meter for the wall and floor. Figure 4 shows the roof of Case C has a higher impact on the global warming per house than the roof of Case A and Case B. This difference is not because of the material choice, but due to the design of the roofs (roof C is 1.7 times larger than roof A). Figure 5 shows that the $CO_2$-emission per squared meter of Case C's roof is lower than the $CO_2$-emission per squared meter of Case A's roof. The area of the walls are almost the same for each Case (Case A 73.20 $m^2$, Case B 70.09 $m^2$ and Case C 71.19 $m^2$) and deviate form the area of their floor and roof. Figure 4 shows that the walls have the largest impact on the global warming of the whole tiny house of all the three cases and this is due to the volume of the walls.
The tiny house of Case B is built on site and the tiny house of Case C is built 5 km of the site. Compared those results to the $CO_2$-emission of the transport of Case A, the emission of transport of Case A is 27% higher to Case B and 96% higher than Case C.

## 5 Discussion

The main objective of this report was to describe the Tiny House Movement in the Netherlands and to examine the impact on the global warming of construction and insulation materials which are used for a tiny

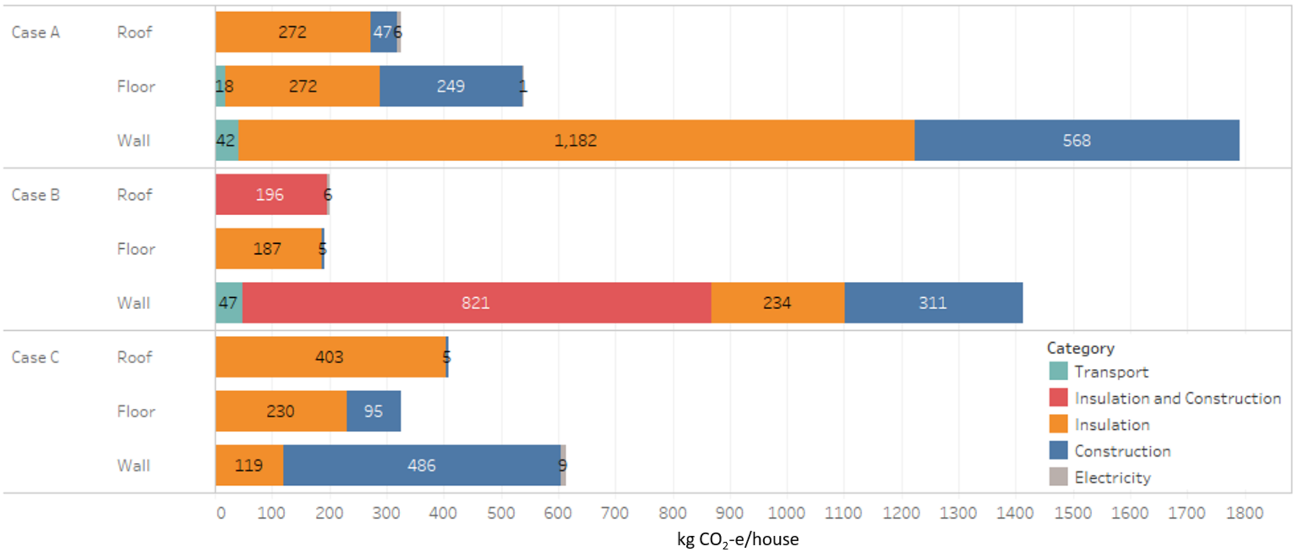


**Fig. 4** Carbon Dioxide of the Construction and Insulation materials used in the cases per house

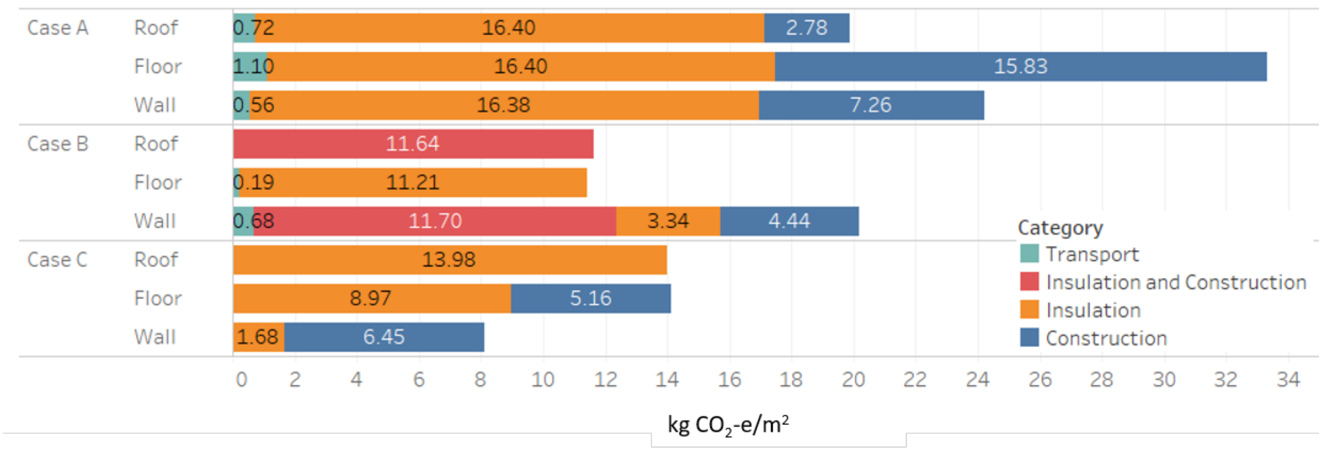


**Fig. 5** Carbon Dioxide of the Construction and Insulation materials used in the cases per squared meter

house.To determine the impact of Tiny Houses data about building materials and the building processes of Tiny Houses in The Netherlands was needed. Although, as shown in Figure 2, there is an growing amount of people who want to live in a tiny house, there were not many people willing to participate in this project. In general, the Tiny House community is very open to help and great selection of Tiny House residents really want to put Tiny Houses on the map. Unfortunately, this study was done in the period of November-January and the tiny house residents have a winter-stop in this specific period in the Netherlands. Probably, the winter-stop, the relative large effort to participate in the project and the lack of time resulted in a disappointing amount of data. Luckily, three persons were willing to provide data about their houses and made it possible to make some steps in the LCA of Tiny Houses.
Regarding the lack of time and data issues, there is chosen to only evaluate the materials in the cradle-to-gate phase. Therefore, the thermal resistance is not part of the scope. This thermal resistance could possible provide more insight into the environmental impact in the use phase. Reclaimed materials were assessed as they were newly bought. The impact of Case B (all building materials) and Case C (PIR), could be in reality less than now is presented.

The $CO_2$-emission of Sheep Wool for Case A is conspicuous when comparing with other studies. In earlier years, sheep wool was a by-product of the sheep meat production. Therefore, using materials that are would have been waste is a sustainable approach. However, nowadays the wool is not waste anymore.Therefore the $CO_2$-emission during the life of the sheep is also taken into account for the calculations. [37] Assuming the wool of a sheep is a byproduct the weight of the $CO_2$-emission would be 85% to 87% lower for Case A [38] [39]. According to Bre Sheep Wool has an impact of 2.09 kg $CO_2/m^2$ [38] and according to Asdrubali et al. the impact of Sheep Wool is 1.94 kg $CO_2$/kg Sheep Wool [39].

## 6 Conclusions

The life cycle analysis is done for three cases of tiny houses. One with only new materials, one with new and reclaimed materials and one with only reclaimed materials. The results show that the tiny house built with only new material has the highest impact on the global warming. Despite of the fact that the materials of the other two cases were also considered as new materials in the analysis. The tiny house with only new materials has a higher impact on the global warming

**Table 3** Results of LCA per squared meter

| | Case A | | | Case B | | | Case C | | |
|---|---|---|---|---|---|---|---|---|---|
| **Section of house** | **Production** (kg $CO_2/m^2$) | **Transport** (kg $CO_2/m^2$) | **Total** (kg $CO_2/m^2$) | **Production** (kg $CO_2/m^2$) | **Transport** (kg $CO_2/m^2$) | **Total** (kg $CO_2/m^2$) | **Production** (kg $CO_2/m^2$) | **Transport** (kg $CO_2/m^2$) | **Total** (kg $CO_2/m^2$) |
| Floor | 32.22 | 1.10 | 33.32 | 11.21 | 0.19 | 11.40 | 14.12 | 0.03 | 14.15 |
| Roof | 19.18 | 0.72 | 19.89 | 11.64 | 0.02 | 11.66 | 14.18 | 0.02 | 14.19 |
| Wall | 23.64 | 0.56 | 24.20 | 19.49 | 0.68 | 20.17 | 8.13 | 0.03 | 8.16 |

**Table 4** Results of LCA for cases A, B and C per squared meter

| | | Case A | | | Case B | | | Case C | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Material** | **Section of house** | **Production** (kg $CO_2/m^2$) | **Transport** (kg $CO_2/m^2$) | **Total** (kg $CO_2/m^2$) | **Production** (kg $CO_2/m^2$) | **Transport** (kg $CO_2/m^2$) | **Total** (kg $CO_2/m^2$) | **Production** (kg $CO_2/m^2$) | **Transport** (kg $CO_2/m^2$) | **Total** (kg $CO_2/m^2$) |
| Beams | Floor | 5.70 | 0.67 | 6.37 | | | | | | |
| | Wall | | | | 3.17 | 0.43 | 3.60 | | | |
| Celit | Roof | 1.50 | 0.14 | 1.64 | | | | | | |
| | Wall | 1.50 | 0.14 | 1.64 | | | | | | |
| Concrete plex | Floor | 1.00 | 0.03 | 1.03 | | | | 5.16 | 0.01 | 5.17 |
| Ecoboard | Floor | 9.13 | 0.40 | 9.53 | | | | | | |
| | Wall | 4.49 | 0.19 | 4.69 | | | | | | |
| Flax insulation | Wall | | | | | | | 1.68 | | 1.68 |
| Glass wool | Floor | | | | 5.87 | 0.00 | 5.87 | | | |
| Gypsum | Roof | | | | | | | 0.20 | 0.00 | 0.20 |
| | Wall | | | | | | | 0.23 | 0.00 | 0.23 |
| OSB-3 | Wall | | | | | | | 4.78 | 0.01 | 4.79 |
| PIR | Floor | | | | | | | 8.97 | 0.01 | 8.98 |
| | Roof | | | | | | | 13.98 | 0.02 | 13.99 |
| Planks | Roof | 1.28 | 0.23 | 1.51 | | | | | | |
| | Wall | 1.27 | 0.23 | 1.49 | 1.27 | 0.17 | 1.44 | | | |
| Plywood | Floor | | | | | 0.19 | 0.19 | | | |
| | Roof | | 0.35 | 0.35 | | | | | | |
| Rock wool | Floor | | | | 5.35 | 0.00 | 5.35 | | | |
| | Wall | | | | 3.34 | 0.00 | 3.34 | | | |
| Sandwich panels | Roof | | | | 11.64 | 0.02 | 11.66 | | | |
| | Wall | | | | 11.70 | 0.07 | 11.78 | | | |
| Sheep Wool | Floor | 16.40 | | 16.40 | | | | | | |
| | Roof | 16.40 | | 16.40 | | | | | | |
| | Wall | 16.38 | | 16.38 | | | | | | |
| Spruce | Wall | | | | | | | 1.45 | 0.02 | 1.46 |

due to the use of Sheep Wool. Transportation has an impact as well, but the impact is lower than the impact of the production of the material itself. An important side note is that now the materials are all bought in The Netherlands. Importing materials from other countries will have a higher impact on the $CO_2$- emission and this is neglected in this study. Building with local products will result in a lower $CO_2$-emission and is therefore more environmentally friendly. Figure 4 shows that the $CO_2$-emission of transport of Case C is just a fraction of the $CO_2$-emission of the transport from Case A and Case B. The beams of Case B have had a trip of over 260 km which results in an impact of 30 kg $CO_2$-e. In combination with the fact that all the materials are assumed as new materials in this analysis, there can be concluded that long distances have a negative impact on the environmental friendly chosen materials.
Sheep Wool can be seen as a natural product since it can be seen as a waste product of the sheep meet production. But nowadays Sheep Wool is not a waste product anymore. And therefore in the decision making phase about materials coming from animals, you always have to ask yourself: "Are the materials actually a byproduct in the manufacturing process or are they main products nowadays"?

## 7 Recommendations

This research gained insights of the Tint House Movement in the Netherlands and experienced a positive stand of participants. It would only be recommended to take into account the winter-stop of the open days of Tiny House residents in further research.
The tiny house movement is growing and encounters bottlenecks such as the Dutch Building Code. Architects and building companies are anticipating on live in smaller houses and they try to find a market in the tiny houses as well. For example Heijmans invented the Heijmans one, a dwelling for one or two persons of 29 $m^2$ which can be replaced from site to site [40]. The difference with a tiny house is that a Heijmans One is higher than 4 meter. You can split the Heijmans One into two pieces for transport. An another example is the Wikkelhouse, it is a house build with compartments so you can chose the length of your house in segments [41]. Most of the companies build smaller houses and call them 'tiny houses'. For further research I should recommend to do a study on LCA and compare the companies with private tiny houses.
In further research, I would highly recommend to assess the whole LCA from cradle-to-cradle and compare the results with the thermal resistance of the materials and take all the parts of the outskirt of a tiny house into account. When a comparison is made with the thermal resistance an advice to the government could be made to change the Building Code and accept tiny houses in the Building Code.
At this time the MPG is only obligated for newly build and renovated building in the Netherlands with area of more than 100 $m^2$. Further research to the MPG for smaller houses as well, should provide more insight into the effect of the MPG of tiny houses and buildings smaller than 100 $m^2$.

## 8 Advice for the University of Twente

Building a living smart campus where students, professors, researchers, companies and enthusiastic people meet each other on a green and sustainable manner is progressive: Sustainable&Together! In contrast with tiny houses I should after this study advise to build with local products which are not coming from animals unless it is guaranteed the animals product is a byproduct. I should build tiny houses with students under leadership of a carpenter. Further investigations needs to lead to the correct insulation materials. Therefore I recommend to check the GWP of insulation material of the company "Everuse". They are the first company who delivers cradle-to-cradle insulation material made of waste materials and is located in the Netherlands [42]. As construction materials I should advise to work with Sawmill Twickle located in Twente. It is a company with the PEFC and FSC quality mark and they guarantee their wood is coming from well-managed forests in a radius of maximum 150 km. [43] As a pilot study I should recommend to make a couple of houses with the same construction and different insulation material to test insulation materials in tiny houses. In deviation with the tiny houses, I should recommend to collaborate with departments of the University of Twente and test new materials such as $CO_2$-neutral concrete.

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