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Carbon Footprint Estimation of a Single-Family House implementing Greener and Innovative Materials

Oszacowanie śladu węglowego domu jednorodzinnego wykorzystującego bardziej ekologiczne i innowacyjne materiały

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Keywords: *Carbon footprint, materials of construction*

Abstract
The construction industry is a large contributor to climate change, but it also presents an opportunity to positively affect changes through innovation in the built environment. It can include new forms of construction that are cleaner and more environmentally friendly, and which support a reduction of waste, different methods to work with innovative materials and find more effective solutions to store renewable energy. This work provides an example of a single-family house located in Tarnów, Poland, incorporating greener and innovative construction materials (recycled plastic bricks, hemp wool, hempcrete and wood), for which the carbon footprint is estimated. The materials selection was focused on the reduction of traditional materials, including concrete and fiberglass.

Słowa kluczowe: *Ślad węglowy, materiały budowlane*

Streszczenie
Branża budowlana w dużym stopniu przyczynia się do zmian klimatycznych, co stanowi również okazję do wprowadzenia pozytywnych zmian poprzez innowacje. Mogą one obejmować nowe formy budownictwa, które są czystsze, bardziej ekologiczne i pomagają zmniejszyć ilość odpadów, różne metody wykorzystania nowych materiałów oraz lepsze sposoby magazynowania energii odnawialnej. Niniejsza praca przedstawia przykład domu jednorodzinnego zlokalizowanego w Tarnowie w Polsce, w którym zastosowano bardziej ekologiczne i innowacyjne materiały budowlane (cegły z recyklingowanego plastiku, wełnę konopną, beton konopny i drewno), dla którego oszacowano ślad węglowy. Wybór materiałów skupił się na redukcji tradycyjnych materiałów, w tym betonu i włókna szklanego.

Introduction

Climate change is an important matter to the modern society and is primarily driven by the human emissions of greenhouse gases. There is an important difference between the composition of greenhouse gases from natural and anthropogenic source. In the natural source, 60% come from water vapor, 26% from carbon dioxide (CO_2), 8% from ozone (O_3), 4.5% from methane (CH_4) and 1.5% from nitrous oxide (N_2O); whereas in the anthropogenic greenhouse, 60% come from CO_2, 15% from CH_4, 12% from halocarbons, 8% from O_3 and 5% from N_2O (Center for Environmental Studies, Florida Atlantic University, NASA Innovations in Climate Education 2023). CO_2, CH_4 and N_2O are emitted mostly in electricity and heat production, transport, manufacturing, construction and agriculture, which is shown in Figure 1. Those sectors are also the one that have the most increased in the last thirty years, hence they need to be the primary targets for technological innovation, mitigation strategies, and fundamental shifts towards a more sustainable and low-carbon future.

The constant use of natural resources over the regeneration capacity of the globe greatly contributes to the emissions. Hence, if the current trends keep up, it will end up in the depletion of the natural resources. In the figure 2, we can observe the substantial increase of CO_2 emissions from coal, oil, gas and cement production over the last two centuries.

The resources consumption and the industrial activities expansion have important implications. Direct impacts include extreme weather, heat and cold waves, wildfires, natural disasters. Indirect impacts through natural systems include air pollution, food and water contamination, distributional shifts of vectors, hosts and pathogens. Indirect impacts through socio-economic systems include food and water insecurity, conflicts due to resource scarcity, forced displacement and mental disorders (Bell, J. E., Brown, C. L., Conlon, K., Herring, S., Kunkel, K. E., Lawrimore, J., Uejio, C. 2018).

The construction world uses a remarkable share of the global natural resources. The materials used usually have an important embodied

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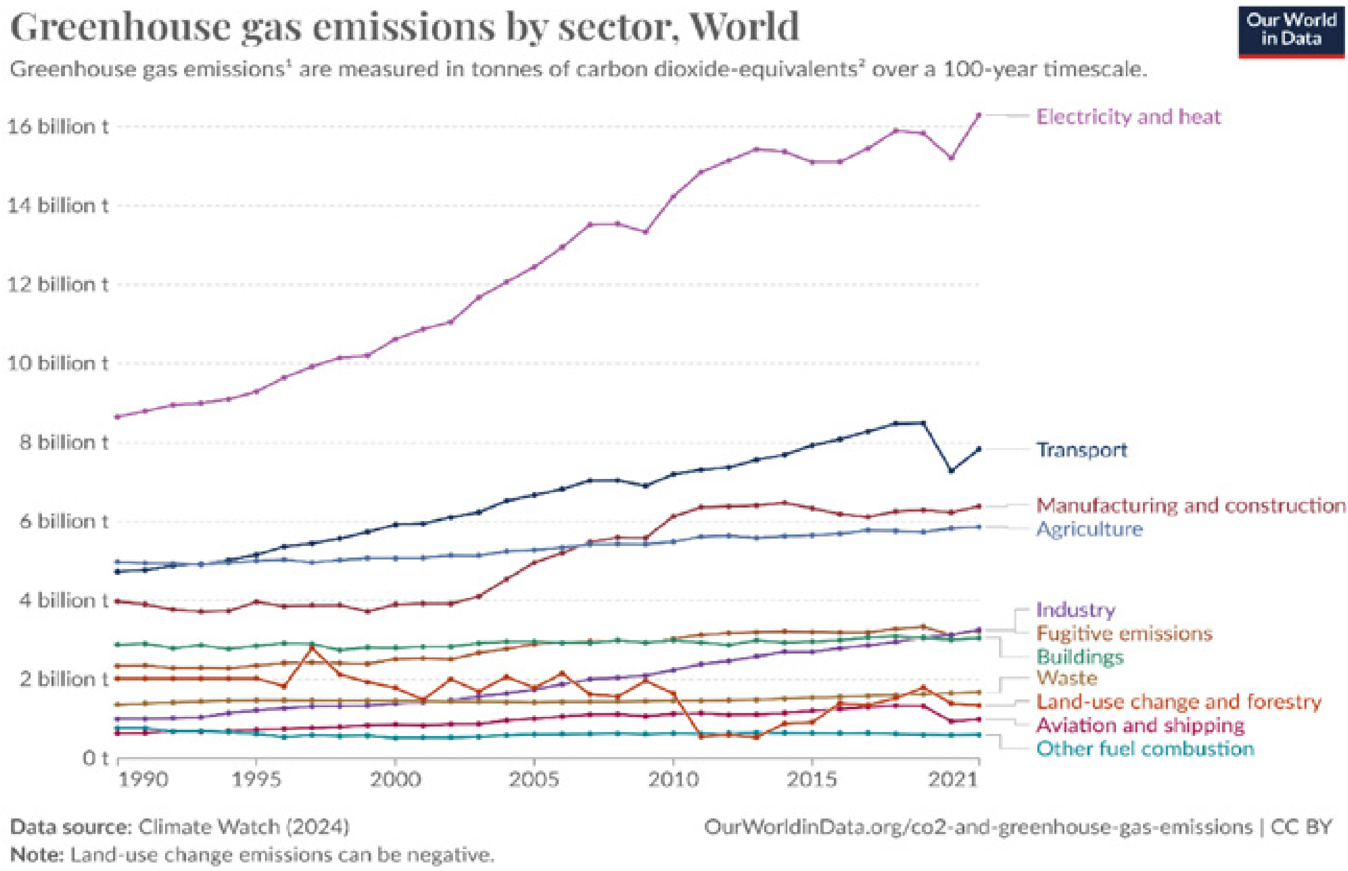

Fig. 1. Greenhouse gas emissions by sector in the world (Our World in Data 2024)

Rys. 1. Emisje gazów cieplarnianych według sektorów na świecie

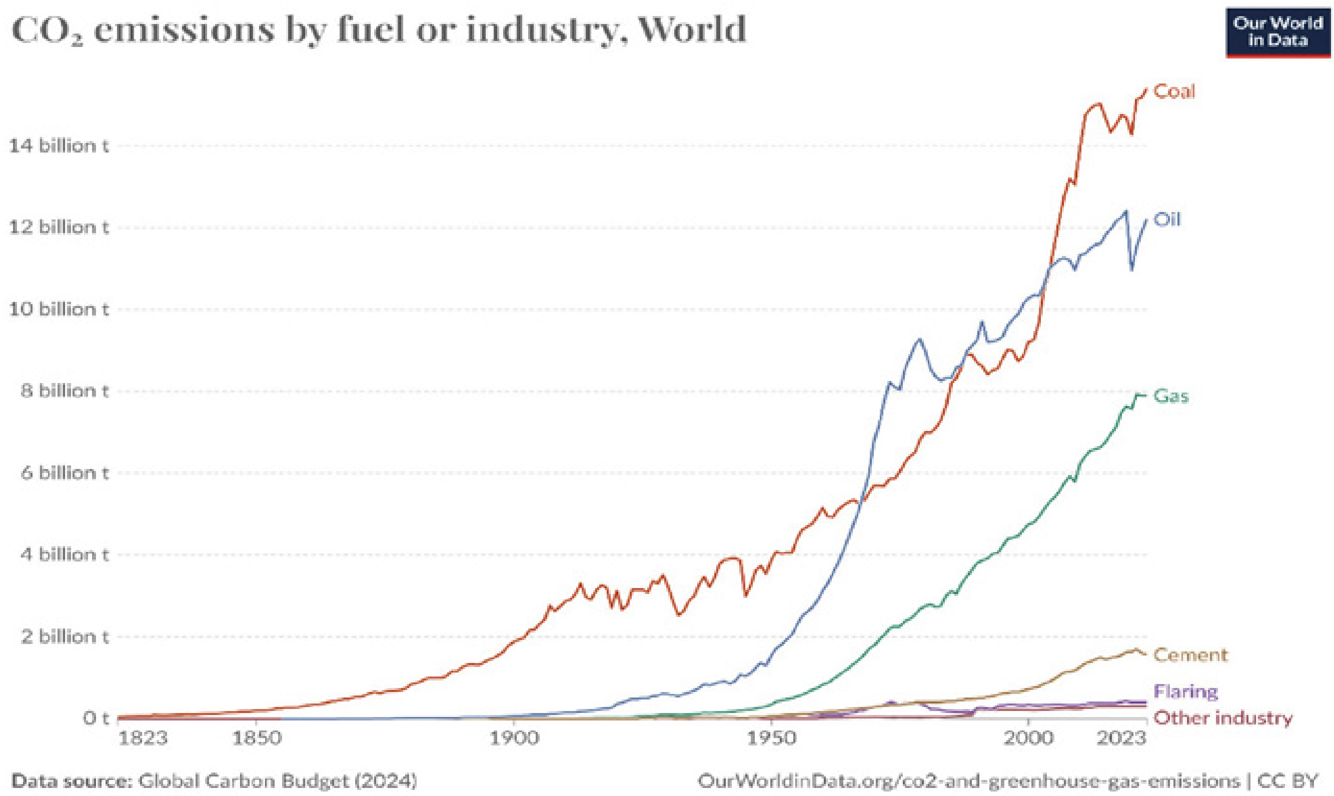

Fig. 2. Carbon dioxide emissions by fuel or industry type in the world (Our World in Data 2024)

Rys. 2 . Emisja dwutlenku węgla według rodzaju paliwa lub gałęzi przemysłu na świecie energy which comprises all energy used to manufacture an useable material throughout the materials lifecycle. Generally, the more manufacturing phases the material has, the bigger the embodied energy is. High embodied energy usually correlates with high emissions. The embodied carbon of a product is the addition of fuel-related and process-related carbon emissions which can be evaluated from cradle to gate, meaning that all tasks from material extraction, transportation, production, and assembling processes are considered until the final product is set to exit the plant (Łukasz Szarek, Łukasz Krysiak, Zbigniew Kledyński, Agnieszka Machowska, Paweł Falaciński 2023), which are the modules A1-A3 in figure 3.

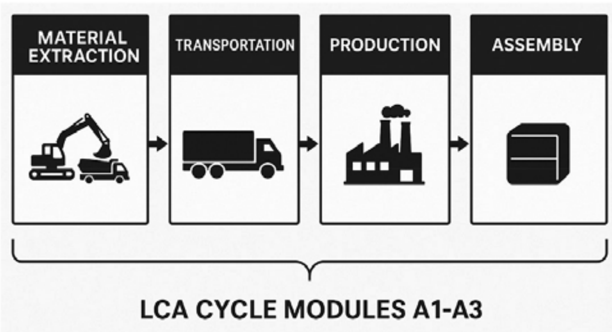

Fig. 3. Product phase in LCA cycle
Rys. 3 . Faza produktu w cyklu LCA

The construction materials with the biggest embodied energy are concrete and metals, especially aluminum and steel. Globally, concrete is accountable for about 5% of the entire anthropogenic carbon dioxide emissions. Yearly, about four billion tons of cement are manufactured, representing approximately 8% of global carbon emissions (Chatham house 2018).

Buildings as a whole are responsible for about 39% of global greenhouse gas emissions: 28% from operational emissions, heating, cooling and powering energy, and the last 11% from construction and materials. They utilize about 25% of global water and 40% of global energy consumption (UN Environment programme 2024) (World green building council 2016). A building's total energy consumption during its entire lifecycle consists of the use phase energy (for heating, cooling, lighting and operating appliances), the embodied energy in construction materials, maintenance, and the building's construction and demolition – with the energy embodied in the construction materials and the energy consumed in the use phase being the greatest contributors. Between 45% to 80% of a building's carbon emissions are produced during the operating phase of its life cycle (Zhongjia Chen, Hongmei Gu, Richard D. Bergman, Shaobo Liang 2020). The percentage depends on different factors, including the building's degree of thermo-insulation, the equipment with building installations, and the energy mix of the country. In the future, the share of embodied carbon (EC) from building materials will increase due to improvements in the building's thermal insulation standards and the decarbonization of energy sources. Hence, improvements in sustainability should first start with the design of buildings and construction projects, where there are opportunities for selecting materials, parameters, solutions and construction methods. For instance, materials and solutions that have a smaller carbon footprint (CF) should be preferred. This can be implemented by selecting natural substances or that do not require a lot of energy to be manufactured (Zima 2021).

The carbon footprint of a product (CFP) is the sum of GHG emissions and removals in a product system, expressed as CO_2 equivalents and based on a life cycle assessment (LCA) using the climate change impact category. In other words, the carbon footprint represents an ecological footprint which includes emissions of CO_2, CH_4, nitrous oxide N_2O and other greenhouse gases, such as industrial gases like sulfur hexafluoride (SF_6), perfluorocarbons (PFCs), hydrofluorocarbons (HFCs) expressed in CO_2 equivalent. A carbon footprint should take into account all emissions of a product from the upstream emissions (raw materials extraction, manufacturing, transportation) to the downstream emissions (product's use phase, end-of-life). Carbon footprint is a portion of all LCA and is usually established on long-lived greenhouse gases using a 100-year global warming potential (GWP) (Kyoto Protocol to the United Nations Framework Convention on Climate Change 1997). LCA differentiates four phases, each of them composed of several sections, benefits and loads extending beyond the system boundary, which is shown in Figure 4.

The Environmental Product Declaration (EPD) is another way of communicating the results of a product's environmental impact throughout its life cycle, from raw material extraction to end-of-life. It consists of quantified information based on LCA in order to compare the environmental performance of various products that perform the same functions. It is independently verified, making it a transparent and trustworthy tool (José M P Sala Lizarraga, Ana Picallo-Perez 2020).

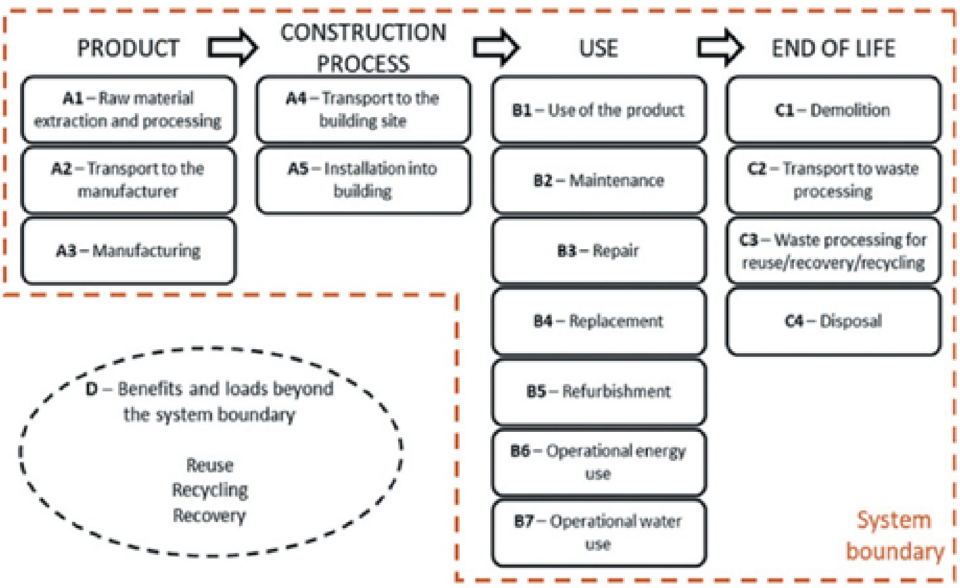

Fig. 4. Four phases and the respective sections (A-D) of LCA in construction works (Łukasz Szarek, Łukasz Krysiak, Zbigniew Kledyński, Agnieszka Machowska, Paweł Falaciński 2023)
Rys. 4 . Cztery fazy i odpowiadające im odcinki (A-D) LCA w robotach budowlanych

This article evaluates the environmental impact of a single-family house in Tarnów, Poland, through a detailed carbon footprint analysis focused on its construction materials. By replacing traditional high-emission materials like concrete and fiberglass with alternatives such as hemp wool, hempcrete, recycled plastic bricks, and sustainably sourced wood, the authors seek to quantify the potential reductions in embodied carbon. The study highlights the significance of material selection during the design phase of buildings and demonstrates how circular design principles can contribute to more sustainable and low-carbon residential construction. By integrating life cycle assessment methodologies (LCA) and emphasizing the growing role of embodied carbon in future buildings, the study contributes to the ongoing discourse on climate-conscious construction and encourages innovation toward carbon-neutral housing solutions.

Methodology

Building's description

Figure 5 - Map of Poland

Rysunek 5 - Mapa Polsk

The single-family house is located in Tarnów, Poland, it has a surface area of 136 m^2 and a net floor area of 118m^2.

The building is designed under circular economy principles and is equipped with photovoltaic panels on the roof, a greywater recycling system and a rainwater harvesting system. The building's materials of construction are selected with the aim of being greener and of having a smaller environmental impact along with a smaller carbon footprint. To limit as much as possible the typical construction materials of concrete and mineral wool, the following materials are chosen. For the load bearing structures, Spruce wood is used as it naturally grows in Poland, it is widely available from sustainably managed forests and can easily be treated against rot and insects. For exterior walls infill, recycled plastic bricks made of HDPE are used (Prathik Kulkarni, Vikas Ravekar, P. Rama Rao, Sahil Waigokar, Sanket Hingankar 2022); by reusing discarded plastic, it reduces existing plastic waste. For the insulation, hemp wool is selected; it has a thermal conductivity coefficient of 0.039 (Ecological building systems 2008) (Matériaux naturels 2008), it is a natural material made of hemp which grows easily and quickly and which doesn't need fertilizer nor pesticide nor much water. For the partition walls and flooring, hemp lime is used as it also has thermal insulating properties, reducing additional insulation for the partition walls. It stores and releases heat as the building cools down, which helps prevent rapid temperature changes, improving the inhabitants' comfort and reducing energy consumption (Jere Komsi, Helsinki Metropolia 2018). Both hemp wool and hemp lime products stabilize the relative humidity level of indoor air, preventing condensation, mold and fungus growth, which is a common issue in Polish houses, maintaining a clean and healthy home environment. A classic cement-plaster on the facades is selected to ensure reliability and durability for finishing the exterior of the house. Usual concrete foundations piers and footings are chosen to guarantee stability, safety and strength.

The thermal insulation of the building is verified by calculating the value of heat transfer coefficient (U):

$$U = \frac{1}{Rt} \, [W/m^2{*}K]$$

With:
R_t – total thermal resistance [m^2*K/W]
The maximum U value in modern building is:

$$U_{max} = 0.2 \, [W/m^2{*}K]$$

As building regulations are subject to change and lower this value over time, it is advised to lower the maximum thermal transmittance value of the design to ensure compliance with future standards.

$$R_1 = \frac{d1}{\lambda 1} = \frac{0.015}{0.93} = 0.016 \, [m^2{*}K/W]$$

$$R_2 = \frac{d2}{\lambda 2} = \frac{0.090}{0.3} = 0.300 \, [m^2{*}K/W]$$

$$R_3 = \frac{d3}{\lambda 3} = \frac{0.25}{0.039} = 6.410 \, [m^2{*}K/W]$$

$$R_4 = \frac{d4}{\lambda 4} = \frac{0.010}{0.93} = 0.011 \, [m^2{*}K/W]$$

$$R_{si} = 0.130 \, [m^2 * K / W]$$

$$R_{se} = 0.040 \, [m^2 * K / W]$$

$$R_t = R_1 + R_2 + R_3 + R_4 + R_{si} + R_{se} = 6.907 \, [m^{2*}K/W]$$

With:
Ri – thermal resistance of each layer of the barrier – [m^2*K/W]
R1 – external layer – cement-plaster with thermal conductivity coefficient 0.93 [w/mK] (Erdem Cuce, Pinar Mert Cuce, Emre Alvur, Yusuf Nadir Yilmaz, Shaik Saboor, Ilker Ustabas, Emanoil Linul, Mohammad Asif 2023)
R2 – bricks layer – recycled HDPE plastic with thermal conductivity coefficient 0.3 [w/mK]
R3 – thermal insulation – hemp wool with thermal conductivity coefficient 0.039 [w/mK]
R4 – internal layer – cement-plaster with thermal conductivity coefficient 0.93 [w/mK]
Rsi – thermal resistance on the internal side of the barrier – 0.13 [m^2*K/W]
Rse – thermal resistance on the external side of the barrier – 0.04 [m^2*K/W]

$$U = \frac{1}{Rt} = \frac{1}{6.907} = 0.145 \, [m^2{*}K/W]$$

U < Umax, hence the proper thermal insulation of building is reached.

Assumptions for carbon footprint's calculations

In the four phases that LCA differentiates, the product phase accounts for about 50% of the embedded carbon. The emissions from both product phase and construction process (modules A1-A5) will be released before 2050 for any building that is completed and ready for use by 2050, and represent the emissions that we must urgently understand and minimize to maintain global warming within 1.5°C (John Orr, Orlando Gibbons, Will Arnold 2020). Therefore the carbon footprint's calculations will focus on raw materials extraction and processing, transport to the manufacturer and manufacturing.

To account for the emissions generated during the transportation of the materials detailed in the following Table 1, an 8% factor of their total embodied carbon was applied. This specific approach was chosen because attempting a more granular estimation for each material's unique journey was considered impractical, as such calculations are prone to high levels of uncertainty and variability in real-world supply chains. While transport emissions (A4) are generally acknowledged to constitute less than 10% of a building's total embodied carbon, this selected 8% contribution, though simplified, adopts a more conservative and robust approach (John Orr, Orlando Gibbons, Will Arnold 2020). It aims to mitigate potential over-optimism by acknowledging real-world factors such as varied material sourcing, potentially longer supply chain distances, or less optimized transport logistics, thereby reflecting a wider spectrum of project scenarios than a purely optimistic estimate.

The estimation of the carbon footprint of the single-family house groups items based on their material type, estimates the final amount of each material, and then multiplies these quantities by the specific carbon emission factor associated with that material. The carbon emission factors, representing the stages A1–A3, were meticulously selected, acknowledging that the range for each factor can be quite broad. For this reason, a given figure is provided for each material, derived either from individual research studies or averages consolidated from various scientific investigations. These coefficients serve as typical carbon factors for the respective materials at their product stage. Crucially, each source for these selected coefficients is transparently cited within the Table 1 presenting the results.

The calculations are as follows:

1. Volume estimation: It is estimated that 110 m^2 of recycled HDPE bricks are necessary for external walls, with dimensions of 19x9x9 cm, giving a total amount of 9.9 m^3.
2. Weight estimation: The density of HDPE ranges from 930 to 970 kg/m^3, with an average of 950 kg/m^3, making a total of 9405 kg of bricks.
3. Carbon footprint emission factor: 0.48 kg CO_2e/kg
4. Total carbon footprint estimation: 9405 * 0.48 = 4514.4 $kgCO_2$ = 4.514 tCO_2

The foundations are made of a concrete slab of 10 cm thick, a gravel base of 20 cm thick, foundation piers and reinforced concrete pad footing. All the wooden elements are calculated based on the same carbon footprint coefficient. It is assumed that every wooden elements are made of Spruce. The amount of wooden structural elements is assumed to be 30 m^3 for the house. Estimates for the quantities of other construction materials were derived from the building's overall size and the dimensions of its walls.

The finishing stages included in the assumptions are flooring and plastering. The estimation does not count additional materials such as asphalt, primer, glue, paint, varnish, adhesive and sealant.

Additional measures to reduce the carbon footprint in the use phase

To save as much water as possible, the house is designed to be equipped with a greywater recycling system and a rainwater harvesting system which becomes functional as soon as the roof is installed, allowing its use during construction phase. Therefore, the amount of water used for cleaning during the construction work is assumed only for the period of time until the roof is installed. It is assumed that 75 Liters per day are needed for approximately 15 weeks, after which the necessary amount of water can be fulfilled by the rainwater: the minimum rainfall in Tarnów is about 36 mm/month (simulation with RETScreen), giving an amount of 4.9 m^3 (36/1000*136 m^2 = 4.9 m^3) of collected water from the roof, representing an average of 163 Liters per day (4.9*1000/30 days = 163 L).

The estimated water consumption for this study is 175.44 m^3/year, considering the Polish average water consumption of 19.66 m^3/month. This figure takes into account a monthly saving of 5.04 m^3 achieved through the implementation of a greywater recycling system, which reduces the demand for black water. The water consumption considered for this study is for 50 years, making a total of 8772 m^3 (175.44 * 50 = 8772 m^3).

Photovoltaic panels installed on the roof are utilized to cover the household's electricity demand of electricity. The building is equipped with a heat pump and a mechanical ventilation system featuring a heat recovery module with 85% efficiency. According to the methodology for calculating energy performance certificates (Rozporządzenie Ministra Rozwoju i Technologii z dnia 28 marca 2023 r. zmieniające rozporządzenie w sprawie metodologii wyznaczania charakterystyki energetycznej budynku lub części budynku oraz świadectw charakterystyki energetycznej 2023), the final energy demands for heating and ventilation, and for heating of domestic hot water are, respectively, approximately 8.3 kWh/(m^2/year) and 13.9 kWh/(m^2/year). Knowing that the usable building's floor area is 118 m^2, the total energy demand is (8.3+13.9)*118 = 2620 kWh/year. With a standard photovoltaic installation of 6.5 kWp for such a building, the annual energy production is about 5850 kWh/year, which significantly exceeds and thus fully covers the building's entire electricity demand. Consequently, the operational emissions associated with electricity consumption will be practically zero. This estimation considers that while solar panels have an initial embodied carbon footprint from manufacturing, this is typically offset by the clean electricity they generate within their first few years of operation (often referred to as carbon payback time). After this period, the electricity produced by the PV system is considered very low-carbon over its remaining lifespan, with a life-cycle emission factor commonly cited around 50 g of CO_2 per kWh (Solaris renewables 2024).

Results and analysis

The total estimated carbon emissions of the building for 50 years is about 33 tCO_2/kg, considering the construction materials, their transportation, water need and electricity produced by solar panels. The carbon emissions of a standard house, based on the same criteria, can be estimated between 120 to 138 tCO_2/kg (Saint-Gobain 2025).

The materials that have the highest embodied carbon are:

- Steel, with a coefficient of 3778 gCO_2/kg
- Float glass, with a coefficient of 1230 gCO_2/kg
- Ceramic tiles, with a coefficient of 613 gCO_2/kg
- Bricks in HDPE, with a coefficient of 480 gCO_2/kg
- Cement, with a coefficient of 405 gCO_2/kg
- Wood, with a coefficient of 392 gCO_2/kg

The initial material selection presented both environmental advantages and disadvantages. For instance, substituting hemp wool for fiberglass resulted in a 5.58 tCO_2 emission saving, given fiberglass's average carbon footprint of 1.95 $kgCO_2/kg$. Conversely, the adoption of recycled HDPE plastic bricks resulted in a 0.51 tCO_2 rise in the overall carbon footprint compared to medium-density Autoclaved Aerated Concrete (AAC) blocks. This increase indicates that the emissions associated with transport and processing recycled plastic outweighed the potential benefits in this specific comparison. A key factor in the total embodied carbon was also the substantial volume of wooden structural elements. In this analysis, we explicitly accounted for the emissions associated with wood's production and logistics, a methodological choice made despite recognizing the significant CO_2 absorption that inherently occurs during the wood's growth cycle.

Table 1 – Carbon footprint of the materials of construction

Tabela 1 – Ślad węglowy materiałów budowlanych

Material	Amount	Unit	Amount	Unit	Carbon footprint emission factor (gCO_2/kg)	Total
Wood	**19268.56**	**kg**			**392.25 (András Polgár 2023) (The engineering toolbox 2013)**	**7.558**
Wooden structural elements in spruce for the house	30	m3	18900	kg		
Wall strip made of spruce	39.28	m	79	kg		
Wooden foldable attic stairs	1	pieces	20	kg		
Wooden external entrance doors	1	pieces	30	kg		
Wooden interior door frames	8	pieces	80	kg		
Wooden paneled interior door leaf	8	pieces	160	kg		
Float glass – double pane	**44.26**	**m2**	885.2	kg	1230 (Antti Ruuska (ed.) 2013)	1.089
Aluminum windows	4.76	m2				
PVC windows	8.27	m2				
Wooden window made of pine wood	1.56	m2				
Single-leaf aluminum doors	6.9	m2				
Aluminum sliding doors	22.77	m2				
Ceramic tiles	**186.99**	**m2**	2337.3	kg	613 (Antti Ruuska (ed.) 2013)	1.433
Ceramic floor tiles	130	m2				
Ceramic wall tiles for the bathroom	51.79	m2				
Ceramic plinths	86.63	m	5.20	m2		
Bricks	**9.9**	**m3**	9405	kg	480 (Carbon Cloud 2023)	4.514
Recycled HDPE bricks 19x9x9cm for external walls	110	m2				
Hemp wool	**104.52**	m3	4180.6	kg	79 (Ilija Bošković, Ana Radivojević 2023) (Y. Florentin, D. Pearlmutter, B. Givoni, E. Gal 2017) (Flavio Scrucca, Carlo Ingrao, Chadi Maalouf, Tala Moussa, Guillaume Polidori, Antonio Messineo b, Claudia Arcidiacono, Francesco Asdrubali 2020)	0.330
Hemp wool to fill in cavities and gaps around pipes, walls and floor	15.11	dm3				
Hemp wool for the external walls	27.5	m3				
Hemp wool for the floor	12	m3				
Hemp wool for the ceiling	30	m3				
Hemp wool for the roof	35	m3				
Hemp lime	**22.2**	**m3**	6660	kg	224 (Y. Florentin, D. Pearlmutter, B. Givoni, E. Gal 2017)	1.492
Hemp lime for the partition walls	12.6	m3				
Hemp lime for the floor	9.6	m3				
Steel	**1206.51**	**kg**			**3778 (Antti Ruuska (ed.) 2013)**	**4.558**
8mm B500SP ribbed reinforcing bars for the foundations	200.0	kg				
Steel dowels	324	pieces	4.9	kg		
Soft steel wire	14.4	kg				
Construction nails	139.4	kg				
Galvanized construction nails	2.58	kg				
Carpentry clasps/clamps	43.94	kg				
Anchors	236.74	pieces	4.7	kg		
Standard roof hatch	1	pieces	25	kg		
Hammered connectors with a steel pin for attaching polystyrene and wool to solid substrates	680.45	pieces	10.2	kg		
Self-tapping sheet metal screws	2531.75	pieces	3.8	kg		
Metal roofing	2036.25	pieces	700	kg		
Roof tile, left and right gable	70	pieces				
Supporting tile for the step	6	pieces				
Ridge cap with clamp for roof tiles	43	pieces				
Roof sides made of coated sheet metal	30.1	m				
End ridge for roof tiles	1	pieces				
Initial ridge locks for roof tiles	1	pieces				

Steel seamless gutter	39.91	m	50	kg		
Steel elbow	3	pieces				
Steel downpipe clamp	5	pieces				
Steel downpipe	10.94	m				
Steel gutter bottom	1	pieces				
Steel gutter drain funnel	3	pieces				
Steel gutter holder	57	pieces				
Air outflow grilles without louvers	10	pieces	2	kg		
Air outflow grilles with shutter	7	pieces	5.6	kg		
Concrete	**15.81**	**m3**				
Sand for concrete – Common grain size 0-31.5mm	4.22	m3	6746.0	kg	2 (Antti Ruuska (ed.) 2013)	0.013
Cement CEM III/C for concrete	2.11	m3	6746.0	kg	405 (Polish Cement Association 2020)	2.732
Gravel for concrete, multi fraction grain size 4-31.5mm	8.43	m3	13492.0	kg	3 (Antti Ruuska (ed.) 2013)	0.040
Water for concrete	1.05	m3	1054.1	kg	0.5776 (Carbon Cloud 2023)	0.001
Additional gravel	**45.05**	**m3**				
Gravel under the concrete slab	45.05	m3	72074.11	kg	3 (Antti Ruuska (ed.) 2013)	0.216
Additional sand	**2.98**	**m3**				
Sand bed under the terrace	2.98	m3	4773.1	Kg	2 (Antti Ruuska (ed.) 2013)	0.010
Mortar	**2.48**	**m3**				
Sand for mortar	1.8	m3	2880	kg	2 (Antti Ruuska (ed.) 2013)	0.006
Cement CEM III/C for mortar	0.45	m3	1440	kg	405 (Polish Cement Association 2020)	0.583
Water for mortar	0.225	m3	225	kg	0.5776 (Carbon Cloud 2023)	0.0001
Plaster	**5.05**	**m3**				
Sand for plaster	3.67	m3	5871.4	kg	2 (Antti Ruuska (ed.) 2013)	0.012
Cement CEM III/C for plaster	0.917	m3	2935.7	kg	405 (Polish Cement Association 2020)	1.189
Water for plaster	0.459	m3	458.7	kg	0.5776 (Carbon Cloud 2023)	0.0003
Additional water	**8780.1**	**m3**	8780100	kg	0.5776 (Carbon Cloud 2023)	5.071
Water for cleaning during construction work	8.1	m3				
Annual water consumption in the household	175.44	m3	8772	m3 for 50 years		
Electricity	**5850**	**kWh/year**				
Annual electricity produced in the household with the PV system	5850	kWh			0 (Solaris renewables 2024)	0
Total						**30.848**
Transportation						
Transportation of materials and equipment	8	%				2.468
Total with transportation						**33.316**

Conclusion & recommendations

The estimated carbon footprint of the designed house, considering the listed items, is about 33 tCO_2. The carbon footprint of a traditional house of the same size would range between 120 to 138 tCO_2. The estimation of the carbon footprint is an approximation of the reality, influenced by various factors such as material sourcing, manufacturing processes, transportation distances, and construction techniques. While it provides a valuable overview of the environmental impact, it is important to acknowledge that the actual carbon footprint might vary. Factors like variations in assumptions, depth of details, considerations of different aspects, and specific construction practices can influence the final carbon footprint. Additionally, ongoing research and technological advancements may refine our understanding of the environmental impact of building materials and construction processes, especially when employing unconventional and innovating ones. Therefore, the estimated carbon footprint should be considered as a guide and a starting point for making informed decisions about sustainable building practices.

Analyzing the initial material selection revealed a mixed environmental impact, highlighting that materials often perceived as greener can, in certain stages of their lifecycle, generate significant carbon emissions due to energy-intensive processing or manufacturing. This underscores the crucial importance of adopting a holistic lifecycle perspective when designing a project, rather than solely focusing on the raw material itself. For instance, while substituting hemp wool for a specific conventional material like fiberglass demonstrated a notable reduction of CO_2 saved in the overall carbon footprint, but the use of recycled HDPE bricks presented a trade-off due to their processing requirements. Ultimately, this analysis underscores that achieving a truly low-carbon building requires a comprehensive evaluation of material choices, considering not only their inherent properties but also the emissions associated with their production, transportation, and end-of-life scenarios.

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