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Life cycle assessment comparison of a typical single storey building

Content

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Publisher:
bauforumstahl e.V. | Sohnstraße 65 | 40237 Düsseldorf
Box 10 48 42 | 40039 Düsseldorf
T: +49 (0)211.6707.828 | F: +49 (0)211.6707.829
zentrale@bauforumstahl.de | www.bauforumstahl.de
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Authors:
Raban Siebers, Bernhard Hauke

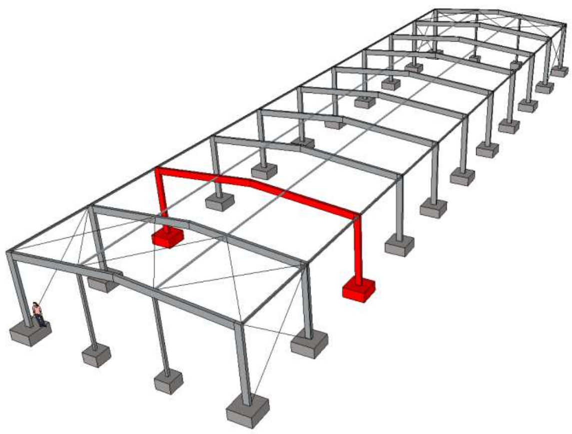
1 | Introduction

With the introduction of Green Building Labels such as “Leadership in Energy and Environmental Design” (LEED) and even more with second generation Sustainable Building Labels such as ”Deutsches Gütesiegel Nachhaltiges Bauen” (DGNB) life cycle assessment (LCA) has become an integral part of the sustainability assessment of buildings. Evaluation and DGNB-labeling of industrial buildings started 2009 in Germany and requires LCA studies for those type of buildings.

To gain knowledge about the environmental impacts of different construction methods for single storey industrial buildings different types of constructions are considered. The focus is here on the structural frame and the employed construction products. In addition, LCA of several types of building envelopes are compared as well as effects of transport.

There is no real meaning comparing construction materials or products only on basis of ecological data. Data bases as the Ökobau.dat of the German Federal Ministry of Transport, Construction and Urban Development (BMVBS) or Environmental Product Declarations (EPD) employ reverence units such as 1 kg or 1 m³. But only comparing complete functional units, e.g. whole structures or a basic module, according to the specific situation, leads to meaningful results. Then, with the different quantities depending on the structural concepts for a comparable function and the data per unit as mentioned above, realistic results are achieved.

For a common single storey building (Figure 1) the simple frame structure can be regarded as a functional unit. The frame structure sustains normal forces, shear forces and moments and is hence stressed in various ways.



basic frame structure

2 | Data base for ecological information

Data bases for this comparison are the Environmental Product Declaration (EPD-BFS-2010111) for structural steel (bauforumstahl.de) and the Ökobau.dat (nachhaltigesbauen.de) of the BMVBS. The specific input data for the EPD are from European steel producers - the owners of this declaration. In the Ökobau.dat which is based on average data, non-European steel producers are included as well. European steel producers, influenced by our environmental and social standards, have invested heavily into their technology over the last decades. Therefore the specific EPD data are much better than the market average as reflected by the Ökobau.dat. For detailed data see also Table 6.

3 | Structural systems

The structural system of a single storey building can be accomplished with different static systems. Depending on the chosen design the required material quantities may vary for a given building size. Also, depending on the construction material a different structural system may be the optimum solution.

The following comparison deals with the main structural system of a typical single storey building with span 15 m, 5 m eaves height, roof pitch 5°, bay distance 6 m, wind load and a snow load 75 kg / m²(Figure 2). Considered are two different structural systems with different construction materials (see Table 1).

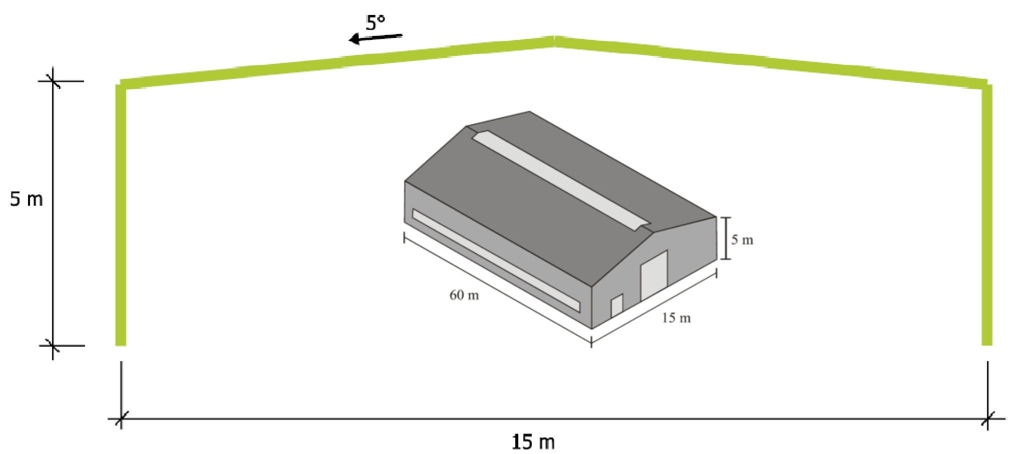


Figure 2: Dimensions of the single storey building and the regarded structural frame.

Table 1: Static systems and construction possibilities

Structural system	Materials
1. Pinned-base portal frame, block foundations	**Structural Steel**
	Frame: grades S 235 and S 460
2. Rigid-base columns, pinned girder, sleeve foundation	**Reinforced Concrete**
	Columns, girder: strength class C30/37
	Reinforced Concrete, Timber
	Columns: strength class C30/37 Glue-laminated timber girders: BS 16

Following some design details of the different structural systems are presented. The associated quantities are the basis for the following life cycle assessment. In addition to the complete structural frame as a functional unit, column and girder are looked at individually. Here, for research purpose the comparison is on individual member level.

Pinned-base portal frame, block foundations

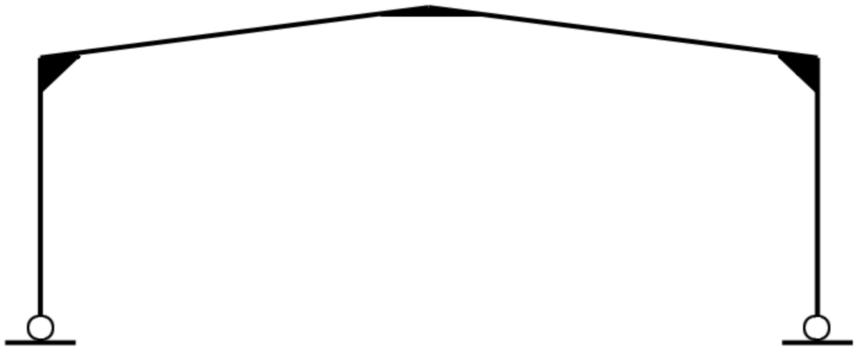


Figure 3: Structural system: pinned-base portal frame

Table 2: Structural steel frame, steel grades S 235 and S 460

Steel frame	Grade S 235	Reinforcement BSt 500	Grade S 460	Reinforcement BSt 500
Columns	IPE 400	-	IPE 400	-
Girder	IPE 450	-	IPE 330	-
Block foundation C 25/30	150 cm x 150 cm x 35 cm	20.3 kg/m³	160 cm x 150 cm x 40 cm	16.7 kg/m³

Figure 4: Single storey building with a steel frame, symbols for steel frame in grade S 235 (left) und grade S 460 (right)

Rigid-based columns, pinned girder, sleeve foundations

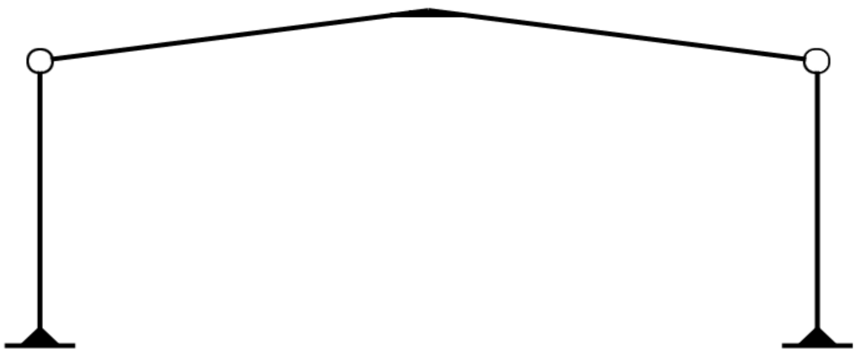


Figure 5: Structural system: rigid-based columns, pinned girder

Table 3: Reinforced Concrete Frame (RC)

Reinforced Concrete Frame		Reinforcement BSt 500
Columns C30/37	40 cm x 40 cm	108.1 kg/m³
RC girder C30/37	Precast concrete unit T 80	202.5 kg/m³
Sleeve foundation C25/30	185 cm x 185 cm x 26 cm sleeve height 80 cm	48.1 kg/m³

Figure 6: Single storey building with a precast RC frame, symbol for RC frame

The design of the foundations (RC, concrete class C25/30, reinforcement BSt 500) is depending on the different super structures. Therefore the foundations are included in the comparison and in fact have to. Any additional minor components, which are possibly required to build those structures (such as screws, rods, starter bars, etc.) are not considered for simplicity. All four different structural systems do provide the same functionality of the single storey building.

Table 4: Reinforced Concrete Timber Frame (RC/Timber), columns RC and girders glue-laminated timber (GL)

Reinforced Concrete Timber Frame			**Reinforcement BSt 500**
Columns C30/37		40 cm x 40 cm	108.1 kg/m³
Timber (GL) girder BS 16	b=14 cm, h_s=71 cm , h_{ap}=101 cm, r_{in}=80 m, l_c=13.94 m	-	-
Sleeve foundation C 25/30	-	191 cm x 191 cm x 24 cm sleeve height 60 cm	53.2 kg/m³

Figure 7: Single storey building with RC/Timber frame, symbol for RC/Timber frame

4 | Life Cycle Assessment Information

The European Committee for Standardization (CEN) has established the Technical Committee "Sustainability of construction works" (CEN/TC 350) which has developed several standards for the sustainability assessment of buildings and construction products. The standard EN 15978 deals with the environmental performance of buildings and defines system boundaries that have to be considered in an LCA. The assessment includes all building-related construction products, processes and services used over the life cycle of the building. The information about products and services is obtained from Environmental Product Declarations. Principles for the preparation of these EPDs are given in EN 15804. As information from product level is directly used for building assessment, both life-cycles have to be structured identically. Therefore CEN/TC 350 has established a module-based life-cycle description (*Table 5*) which is composed of five information modules. The building life cycle starts with the extraction of raw material, covers the construction and use stages and ends with deconstruction and waste processing. In the scheme of complete building assessment information the module five, which comprises benefits and loads that arise from the reuse and recycling of the construction products, has to be taken into account.

Table 5 : Life cycle stages for building products and buildings according to EN 15804 and EN 15978

Building Assessment Information				
Building Life Cycle Information				
Product stage	**Construction Process stage**	**Use stage**	**End of Life stage** (Building)	**Benefits and loads**
A1: Raw material supply	A4: Transport	B1: Use	C1: De-construction, demolition	D: Reuse, recovery recycling
A2: Transport	A5: Construction, installation	B2: Maintenance	C2: Transport	
A3: Manufacturing		B3: Repair	C3: Waste processing	
		B4: Replacement	C4: Disposal	
		B5: Refurbishment		
		B6: Operational energy		
		B7: Operational water		

As usual in this study, the environmental indicators non renewable Primary Energy, Global Warming Potential (GWP), Ozone Depletion Potential (ODP), Acidification Potential (AP), Eutrophication Potential (EP) and Photochemical Ozone Creation Potential (POCP) are considered.

The Global Warming Potential describes the contribution of emissions to the greenhouse effect. It is indicated in the unit kg CO2-Equivalent, which means that all the gases released concerning to the strength of their global warming effect are put into a relationship to CO2.

The non renewable primary energy requirement includes the amount of non renewable primary energy, which is used in the life cycle of a product. There is a distinction between non-renewable and renewable primary energy. The impact category "primary energy, non renewable" includes mainly the use of the natural gas, petroleum, coal and uranium. The impact category "primary energy renewable" contains the energy from wind, hydro, solar and biomass.

The earth's ozone layer protects the environment from excessive global warming and harmful radiation that can result in the development of tumours and the impairment of photosynthesis. Substances such as chlorofluorocarbon (CFC) that can destroy the ozone in the atmosphere should be reduced. The ozone depletion potential (ODP) is described by means of the so called trichlorofluoromethane-equivalent (R11-equivalent).

In order to reduce harmful environmental impacts, the amount of air pollutants released, such as sulphur or nitrogen compounds, is to be reduced. These react in the air to form sulphuric and nitric acid and fall to ground as “acid rain”. Acid rain is one of the reasons for forest dieback, fish mortality or deterioration of historical buildings. The acidification potential is given in SO2-equivalents.

Eutrophication (overfertilisation) of waters and soils leads to an extensive algae growth – the waters become a “dead zone”. Phosphorus and nitrogen compounds are the main cause for eutrophication. The eutrophication potential (EP) is expressed in PO4-equivalents.

If the ozone concentration in the atmosphere is too low, this can be dangerous for the environment. (See ODP description) If, however, the ozone concentration near the ground it is too high, this can be harmful to humans and animals (summer smog). The photochemical ozone creation potential (C2H4-equivalent) rates the amount of harmful trace gases, as for example nitric oxide hydrocarbon, which can, in combination with ultraviolet radiation, cause the formation of ground-level ozone. For all required data see table 6.

The consideration of the material product stage (A1-A3, Table 5) only is regarded obligate according to EN15804 for the environmental evaluation of construction material in an EPD. Whereas further stages such as construction (A4-A5, Table 5), use (B1-B7, Table 5) and building end-of-life (C1-C4, *Table 5*) form the so called Building Life Cycle Information, the actual Building Assessment Information must, according to EN15798, also include the end-of-life scenario of the construction materials (Module D, benefits and loads, Table 5). After the building has been decommissioned and deconstructed the construction products and materials are separated into the different material fractions and, as possible, are designated for new applications. Different scenarios must be assumed. According to the new EU Waste Framework Directive reuse of materials has to be preferred. Otherwise recycling as a material, preferably without loss of quality, is the next choice before recovery (e.g. energy) and disposal. Each of those scenarios is associated with additional benefits or loads which have to be considered when assessing the total environmental impact of a building.

Reuse means that construction products are used again with the same shape and the same purpose for new buildings as in the old. Only minor efforts and emissions are required. Recycling involves processing used materials into new products. In a strict sense, recycling of a material would produce a fresh supply of the same material. However, for many construction products this is difficult or too expensive, so “recycling” often also involves producing different materials with lower quality instead. This is then also called down-cycling. When materials cannot be recycled, recovery of at least certain values of the material can be a strategy to reduce waste. Most common is the recovery of energy by incineration of construction products, thus producing energy but also CO2.

By its material value and its matchless properties, for Steel products recycling and reuse is the only usual and acceptable way of treatment (Page 11). For wooden components incineration is the best way to avoid landfill and regain energy. The Ökobau.dat includes the fitting dataset. According to statistics from the ministry for environment Baden-Württemberg 71% of the Concrete is down-cycled as filler material or concrete aggregate. 29% of the accrued concrete rubble is disposed. To create a practical end of life value for concrete three different datasets of the Ökobau.dat (Chapter 1) are used. The dataset for building rubble processing is proportionally combined with a negative gravel dataset and the dataset for landfill of building rubble (Table 6). This approach is according to the new version of the DGNB label for new Office buildings 2012.

Table 6: Environmental data for construction products from EPD and Ökobau.dat 2011

Material	Comment	Reference Unit (RU)	Primary Energy ,not renewable	Primary Energy ,renewable	Total Primary Energy	Global Warming Potential (GWP)	Ozone Depletion Potential (ODP)	Acidification Potential (AP)	Eutrophication Potential (EP)	Photochemical Ozone Creation Potential (POCP)
			[MJ/RU]	[MJ/RU]	[MJ/RU]	[kg CO_2-Äqv./RU]	[kg R11-Äqv./RU]	[kg SO_2-Äqv./RU]	[kg PO_4-Äqv./RU]	[kg C_2H_4-Äqv./RU]
Structural Steel	**EPD-BFS-2010111**	kg	11.78	0.58	12.36	0.80	4.23E-08	1.79E-03	1.58E-04	2.98E-04
Production		kg	19.48	0.65	20.13	1.68	3.19E-08	3.47E-03	2.89E-04	7.55E-04
Benefits & Loads	11% Reuse, 88% Recycling	kg	-7.70	-0.08	-7.78	-0.88	1.04E-08	-1.68E-03	-1.31E-04	-4.57E-04
ConcreteC 25/30	**Ökobau.dat 2011**	**kg**	**0.45**	**-0.01**	**0.44**	**0.12**	**2.41E-09**	**2.32E-04**	**3.35E-05**	**2.35E-05**
Production	1.4.01 Transit-mix concrete C25/30	2365 kg/m³	1228	22.40	1250.4	240	6.43E-06	4.26E-01	6.04E-02	4.36E-02
		kg	0.52	0.01	0.53	0.10	2.72E-09	1.80E-04	2.55E-05	1.84E-05
Benefits & Loads	9.5.01 Building rubble processing Ökobau.dat 09	kg	0.05	0.00	0.05	0.03	-3.77E-10	6.81E-05	9.96E-06	5.07E-06
	9.5.02 Building rubble landfill	kg	0.20	0.01	0.21	0.02	1.10E-11	9.27E-05	1.30E-05	1.16E-05
	1.2.01 Substitution of gravel	kg	-0.22	-0.03	-0.25	-0.01	-6.16E-11	-3.20E-05	-3.89E-06	-2.60E-06
	(Building rubble processing 71% +Substitution of gravel71%) +Landfill 29%	kg	-0.07	-0.02	-0.09	0.02	-3.04E-10	5.18E-05	7.98E-06	5.07E-06
Concrete 30/37	**Ökobau.dat 2011**	**kg**	**0.49**	**-0.01**	**0.48**	**0.13**	**2.63E-09**	**2.45E-04**	**3.53E-05**	**2.49E-05**
Production	1.4.01 Transit-mix concrete C30/37	2365 kg/m³	1318	23.90	1341.9	262	6.93E-06	4.58E-01	6.46E-02	4.70E-02
		kg	0.56	0.01	0.57	0.11	2.93E-09	1.94E-04	2.73E-05	1.99E-05
Benefits & Loads	9.5.01 Building rubble processing Ökobau.dat 09	kg	0.05	0.00	0.05	0.03	-3.77E-10	6.81E-05	9.96E-06	5.07E-06
	9.5.02 Building rubble landfill	kg	0.20	0.01	0.21	0.02	1.10E-11	9.27E-05	1.30E-05	1.16E-05
	1.2.01 Substitution of gravel	kg	-0.22	-0.03	-0.25	-0.01	-6.16E-11	-3.20E-05	-3.89E-06	-2.60E-06
	(Building rubble processing 71% +Substitution of gravel71%) +Landfill 29%	kg	-0.07	-0.02	-0.09	0.02	-3.04E-10	5.18E-05	7.98E-06	5.07E-06
Rebars	Ökobau.dat 2011	**kg**	**12.42**	**0.99**	**13.41**	**0.87**	**7.85E-08**	**1.64E-03**	**1.39E-04**	**2.74E-04**
Production	4.1.02 Rebar steel	kg	12.42	0.99	13.41	0.87	7.85E-08	1.64E-03	1.39E-04	2.74E-04
Benefits & Loads	100% collection rate no net scrap gain	---	0.00	0.00	0.00	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Glue-laminated timber	**Ökobau.dat 2011**	**kg**	**0.71**	**19.71**	**20.42**	**-0.28**	**4.98E-11**	**1.40E-03**	**2.17E-04**	**1.00E-04**
Production	3.1.04 Glue-laminated timber	515 kg/m³ density at 12% moisture content	4966	10508	15474	-770	6.90E-07	7.25E-01	8.03E-02	7.04E-02
		kg	9.64	20.40	30.05	-1.50	1.34E-09	1.41E-03	1.56E-04	1.37E-04
Benefits & Loads	3.4.03 Eol wooden composites in incineration plant	kg	-8.93	-0.69	-9.62	1.22	-1.29E-09	-1.07E-05	6.15E-05	-3.67E-05

For structural steel (sections and plates) a truly functioning recycling management has been established for many decades in Europe. Here the collection rate is 99% - with other words: from 100 tons structural steel used in a building 99 tons will be recovered after dismantling. Then, in average, 11% of structural steel products are reused again directly for structural purpose and 88% are used for closed loop material recycling (see EPD Structural Steel). For structural steel recycling means the re-melting of used steel (scrap) and subsequent rolling of new sections or plates. Because of steel recycling the production of new steel from iron ore in the blast furnace (BF+BOF) is reduced. This results in less energy consumption and emissions. Because of the modern thermo-mechanical rolling processes even improvements of material properties (up-cycling: e.g. S235 becomes S460) are possible. Landfill or disposal are no options for structural steel because of its inherent economic value.

When a material can be recycled as described above, the use of new raw materials, the consumption of energy and the emission of CO2 can be reduced. The scrap which was necessary for the production must be subtracted (e.g. 460 kg used steel per ton, see example in Figure 8) from the 88% of steel scrap which is recycled. The remaining net scrap (420 kg used steel per ton) and also steel products which can be reused (110 kg) are available to avoid steel

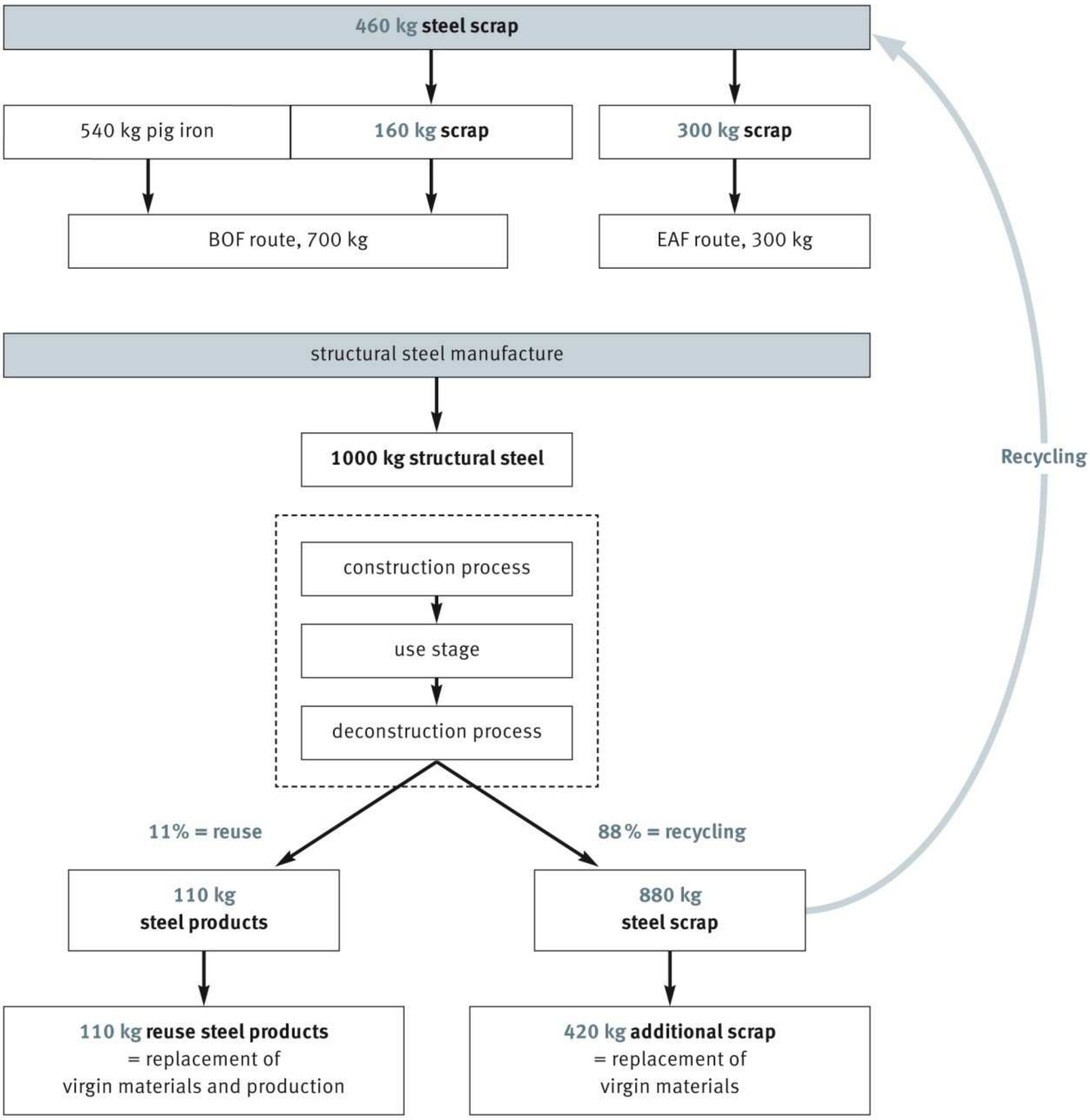


Figure 8: Schematic determination of the Recycling Potential (net scrap & reused steel products replacing new production from iron ore)

production from primary resources. This is called recycling potential (and actually also reuse), see Figure 8. The basic idea of the recycling potential concept is that environmental loads are allocated to each material cycle as they are in a net balance of a cradle-to-cradle frame. As for steel, in the first necessary step of production in the blast oxygen furnace (BOF) process, the total amount of energy consumption or emissions is relatively high. This structural steel is then used for example in a building.

Let us now assume the collection rate was 100% when this building is deconstructed. Hence the secondary raw material used steel is fully available for recycling. Consequently only the difference between structural steel (sections and plates) as a construction product and used steel as a material remaining must be credited to this first life cycle. If the remaining used steel is then in the second step re-melted in the electric arc furnace (EAF) the amount of energy consumption or emissions is lower than for the BOF process. This is because used steel as a material is available free of burdens. The so produced structural steel as a construction product is used again, this time perhaps for a bridge. Here the collection rate is also assumed to be 100%. Hence used steel is available in the same way as before. But now only the effort of producing structural steel from used steel in the EAF must be credited to the second life cycle.

On the other hand, if the collection rate was zero - used steel is lost - the full effort of producing structural steel from iron ore again had to be credited, no matter the lost used steel came from BOF or EAF route. In contrast to the recycled content approach, which only considers the input of secondary material in the production process, the above described recycling potential approach does not credit the simple use of resources but their loss. Or in other words: not using the material but loosing penalised.

Even if the consideration of the recycled content seems to be simpler at the first glance - it is not in line with overall aims of resource efficiency and waste prevention for collection of used materials is not taken into account. Here recycling potential as described above comes in, using contemporary market average data as demanded in EN 15804. This means material collection and recycling cannot be treated as a hypothetical matter of the far future but must be based on proven facts of today. Consequently, changes in average collection or recycling rates or the market share of EAF vs. BOF route etc. will lead to an adjusted determination of the contemporary recycling potential values.

The steel frame with different grades (S 235, S 460) is compared with a reinforced concrete frame (RC) and an RC-timber frame (RC/Timber), see also Chapter 6. The foundations are in accordance with the construction of different sizes and are taken into consideration.

In this comparison of structural systems with different construction materials the recyclability of structural steel without losses in material properties plays an important role. Moreover, because of its high strength structural steel allows ultra-slim and for that reason material-efficient structures. Benefits and loads at the end of life of the product are first displayed separately and then summed up for evaluation purpose with the values for the product stage. In the EN15978 this separate display of the individual modules is requested, but a common evaluation allowed. Thus the entire life cycle of a building material, including recycling or disposal is depicted as one total value. For better comparison with different structures and buildings the values per frame are converted to values per square meter floor area. Figures 10-15 show the environmental indicators as mentioned in chapter 4 including the benefits or loads for the end of Life scenarios recycling (Steel), incineration (Timber) or down-cycling as gravel (Concrete) per square meter gross floor area (GFA).

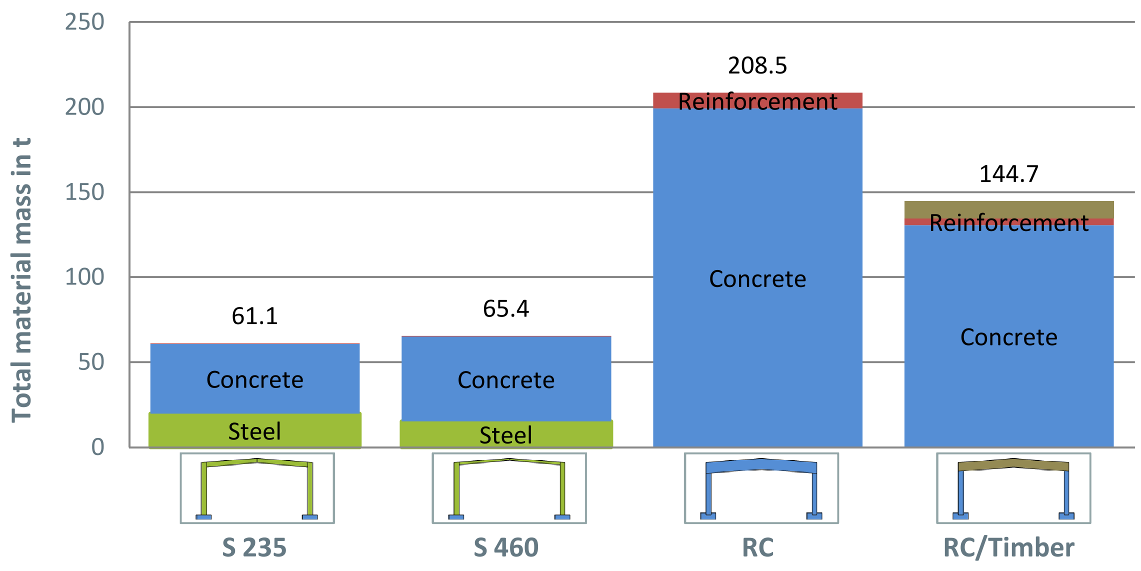


Figure 9: Quantities for the structural systems: frames and foundations, in t

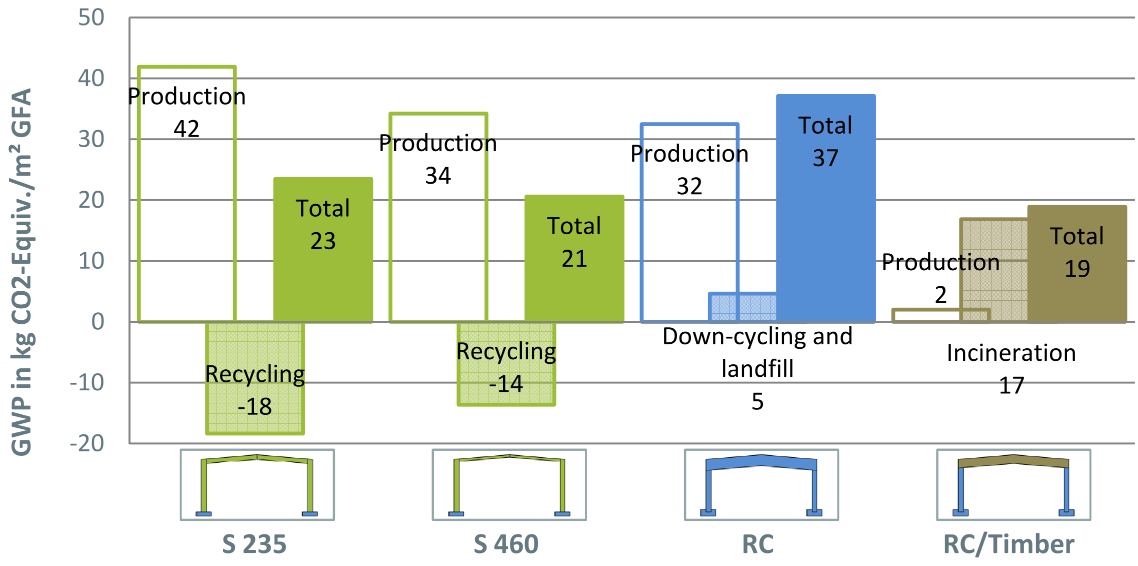


Figure 10: Global Warming Potential for the Product Stage (A1-A3) and separately Benefits & Loads (D) from recycling (steel), incineration (timber) or rubble processing combined with an replacement of gravel (concrete) in kg CO2-Equivalent per m² gross floor area

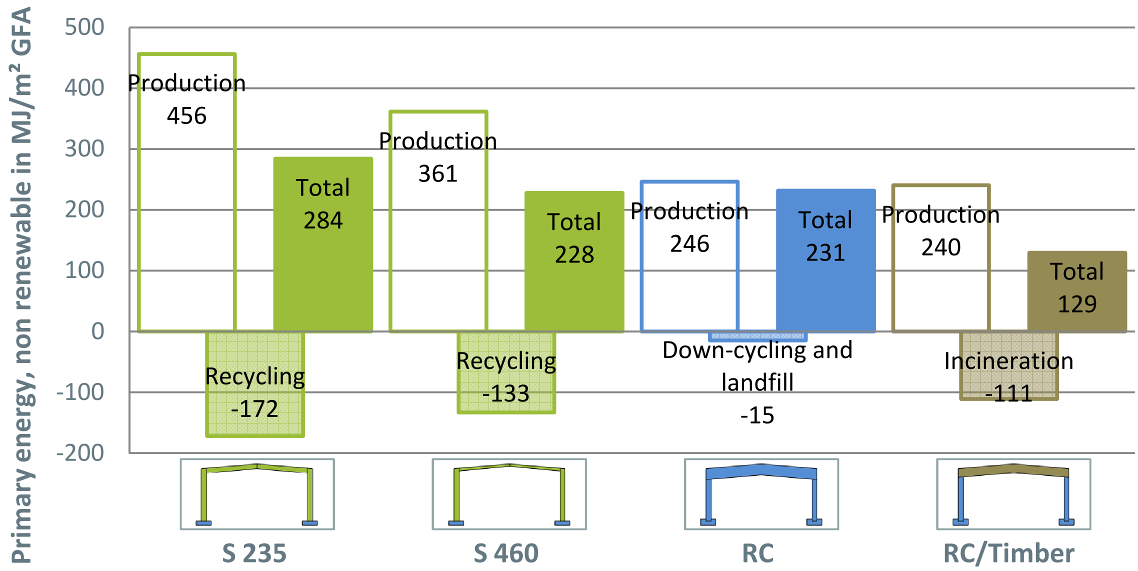


Figure 11: Total Primary Energy for the Product Stage (A1-A3) and separately Benefits & Loads (D) from recycling (steel), incineration (timber) or rubble processing combined with an replacement of gravel (concrete) in MJ per m² gross floor area

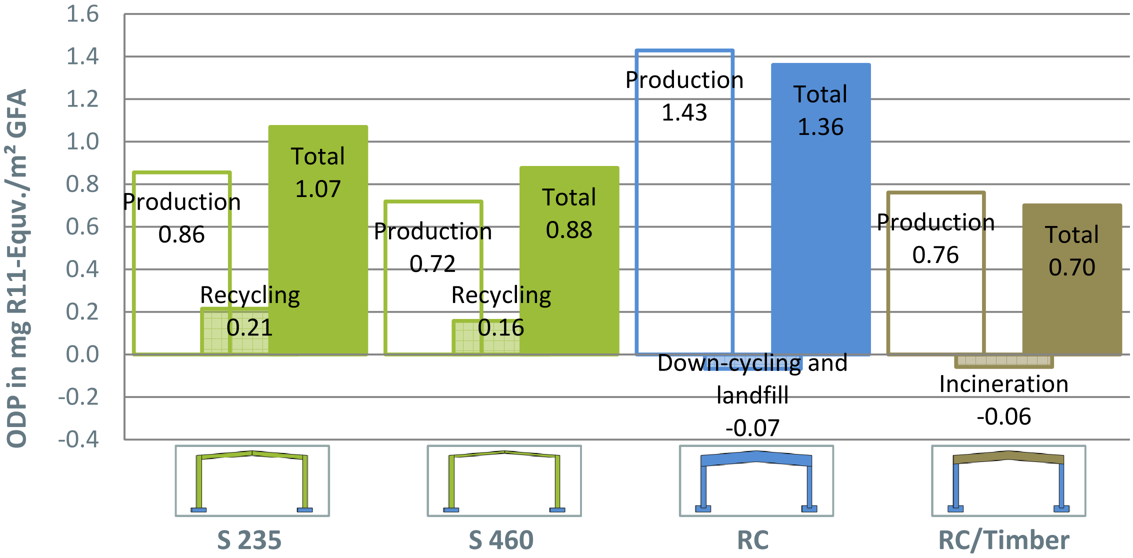


Figure 12: Ozone Depletion Potential (ODP) for the Product Stage (A1-A3) and separately Benefits & Loads (D) from recycling (steel), incineration (timber) or rubble processing combined with an replacement of gravel (concrete) in mg R11-Equiv. per m² gross floor area

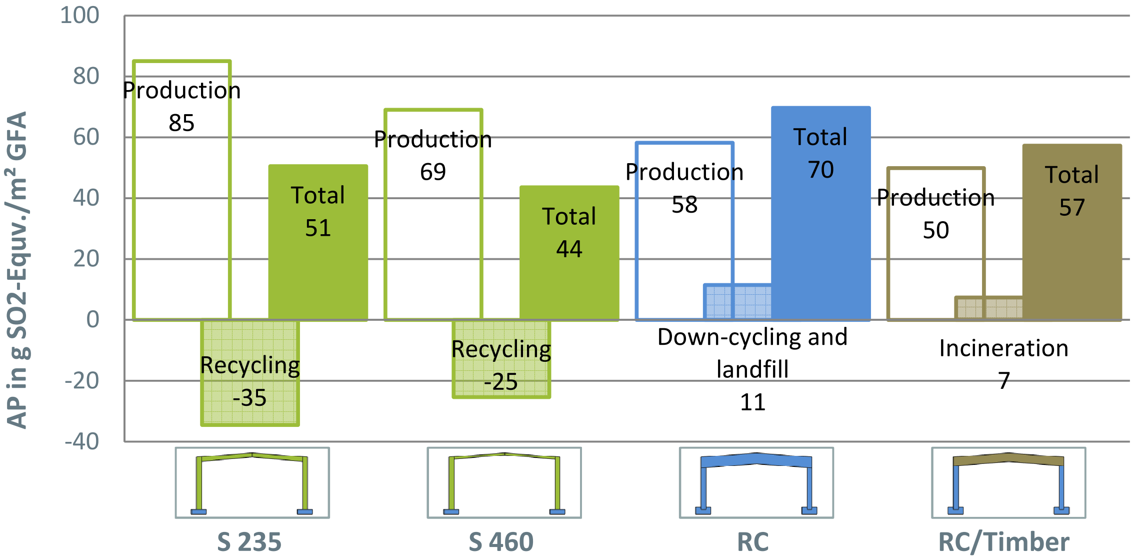


Figure 13: Acidification Potential (AP) for the Product Stage (A1-A3) and separately Benefits & Loads (D) from recycling (steel), incineration (timber) or rubble processing combined with an replacement of gravel (concrete) in g SO2-Equiv. per m² gross floor area

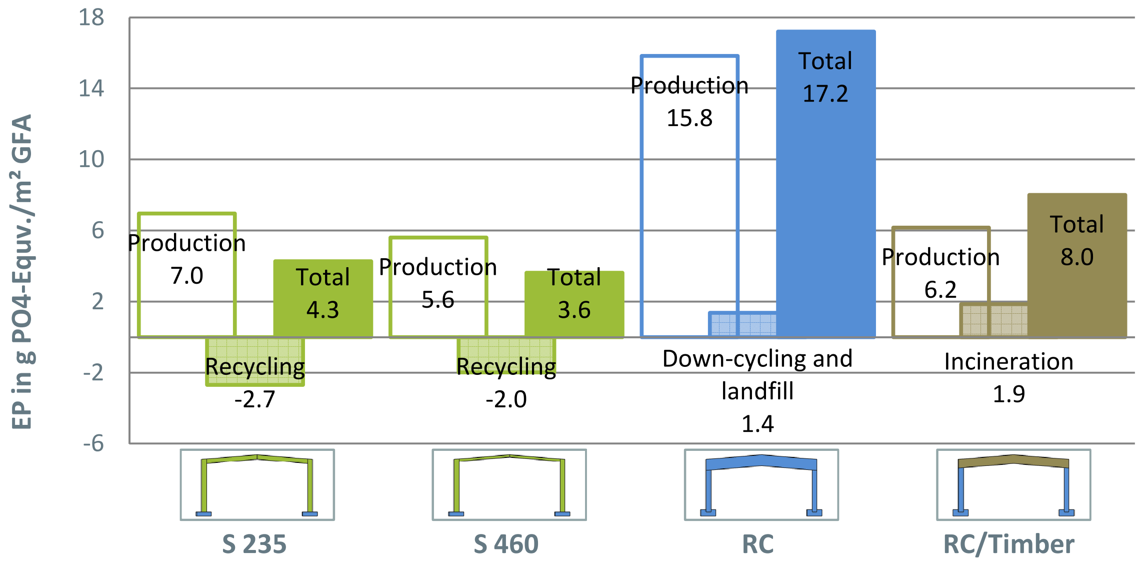


Figure 14: Eutrophication Potential (EP) for the Product Stage (A1-A3) and separately Benefits & Loads (D) from recycling (steel), incineration (timber) or rubble processing combined with an replacement of gravel (concrete) in g PO4-Equiv. per m² gross floor area

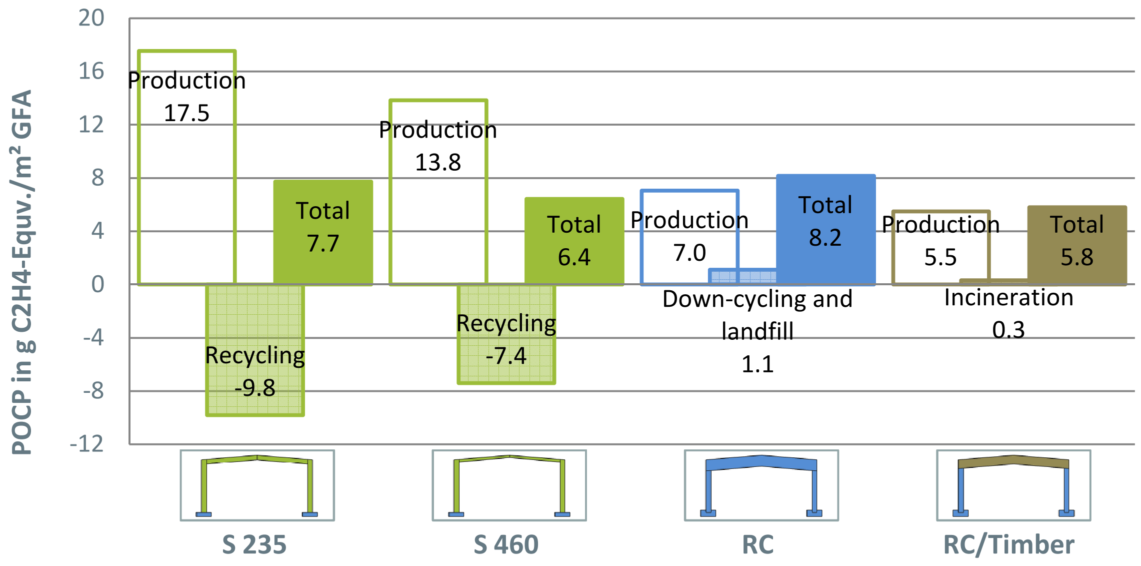


Figure 15: Photochemical Ozone Creation Potential (POCP) for the Product Stage (A1-A3) and separately Benefits & Loads (D) from recycling (steel), incineration (timber) or rubble processing combined with an replacement of gravel (concrete) in g C2H4-Equiv. per m² gross floor area

Looking at all environmental indicators none of the structural systems with different construction materials is in a clear advantage. High strength steel S460 seems recommendable compared to normal strength S235. In Global Warming Potential (GWP), Ozone Depletion Potential (ODP), Acidification Potential (AP) and especially in Eutrophication Potential (EP) the steel constructions perform very well.

6 | Column without foundation – single structural member

For the columns (combined compression and bending member) the steel column as compared to the reinforced concrete column achieves much lower masses and better results for Global Warming Potential. For Total Primary Energy demand the reinforced concrete column superficially seen gains the advantage. However the foundations, that are not considered here, are larger for the RC columns here. A true statement can therefore only be taken in relation to the overall structural system.

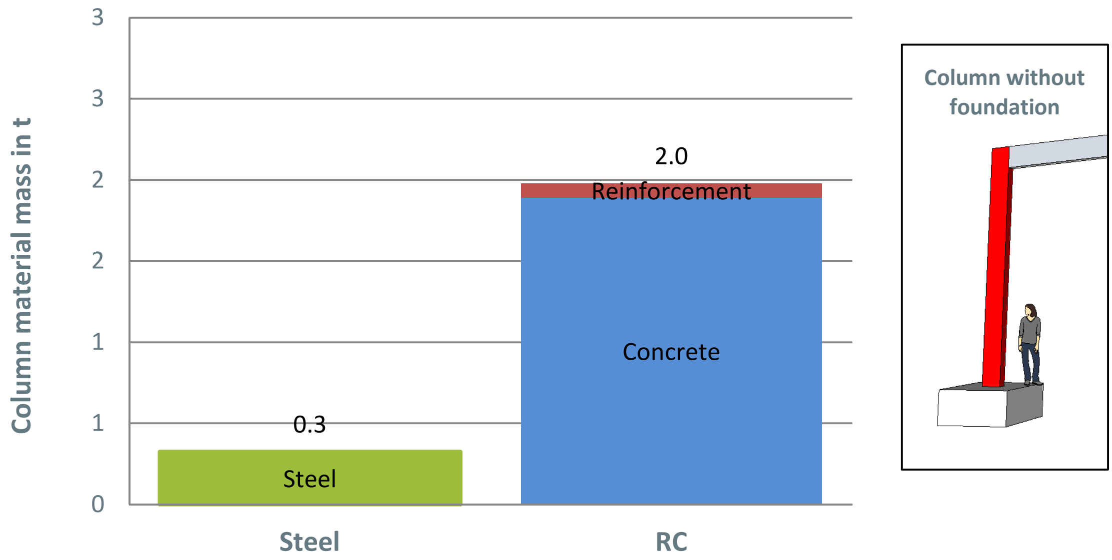


Figure 16: Quantities for columns without foundation, in t

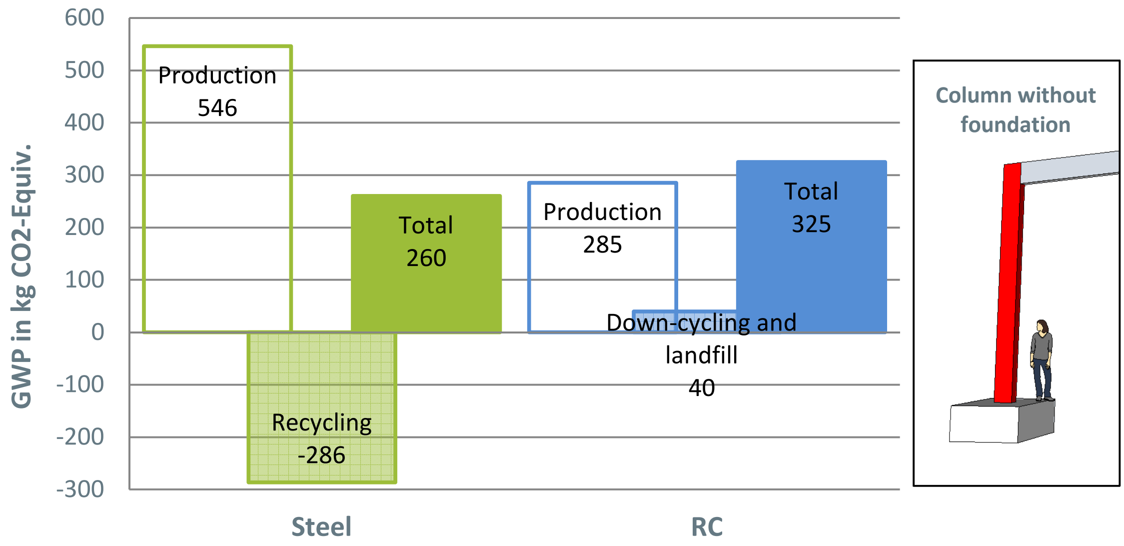


Figure 17: Global Warming Potential for the Product Stage (A1-A3) summed up with Benefits & Loads (D) from recycling (steel), incineration (timber) or rubble processing (concrete) for one column without foundation, in kg CO2-Equivalent

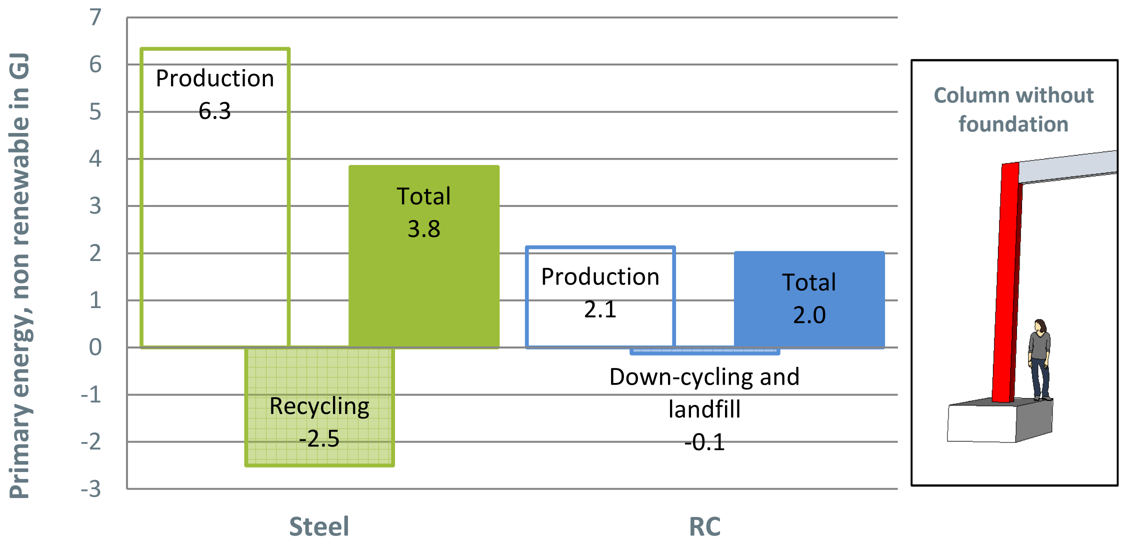


Figure 18: Total Primary Energy for the Product Stage (A1-A3) summed up with Benefits & Loads (D) from recycling (steel), incineration (timber) or rubble processing (concrete) for one column without foundation, in GJ

7 | Girder – single structural member

For girders (bending member) especially the large material quantities of the reinforced concrete and the good performance of the glue-laminated timber truss is noticeable. The use of a section with high steel grade reveals particularly here for the bending member. It is evident that if only single members are looked at the results may be distorted.

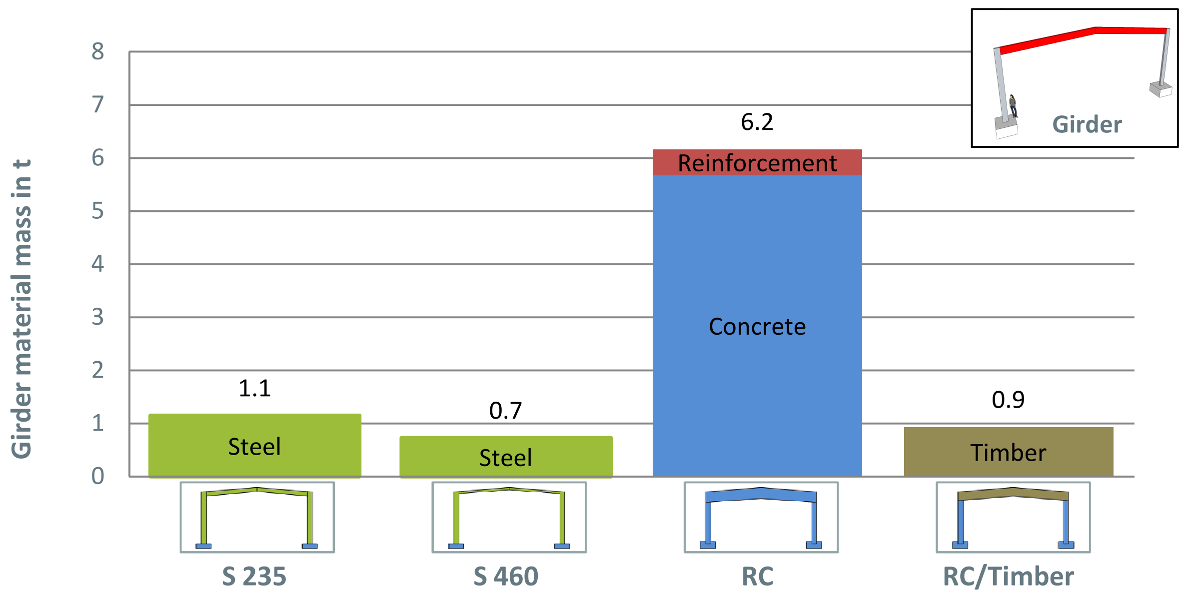


Figure 19: Quantities for a girder, in t

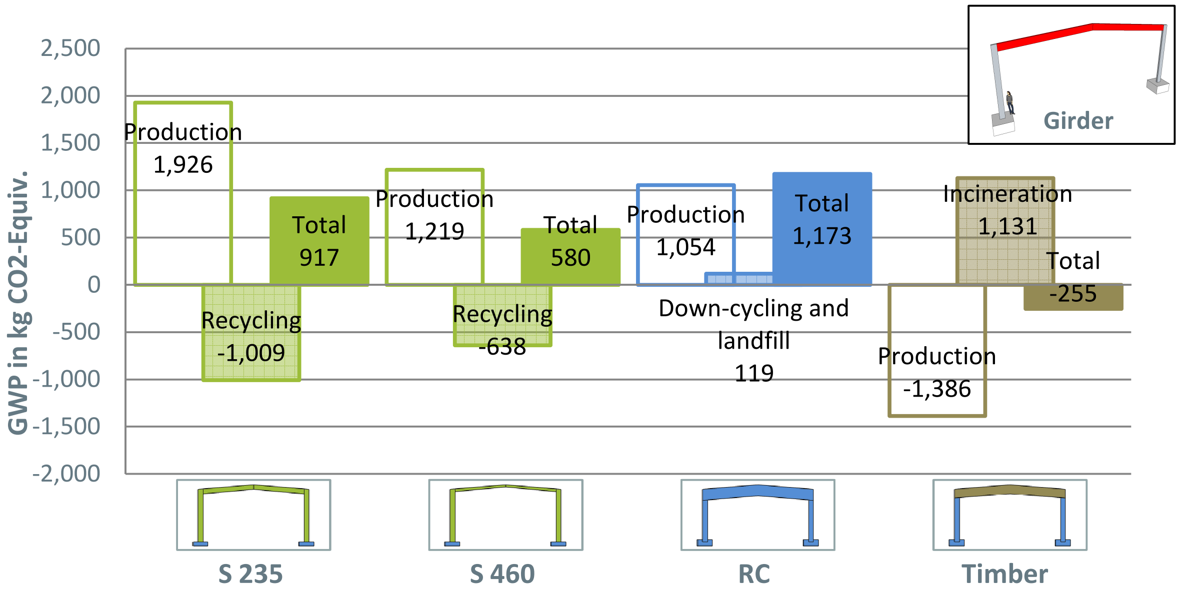


Figure 20: Global Warming Potential for the Product Stage (A1-A3) summed up with Benefits & Loads (D) from recycling (steel), incineration (timber) or rubble processing (concrete) for one girder, in kg CO2-Equivalent

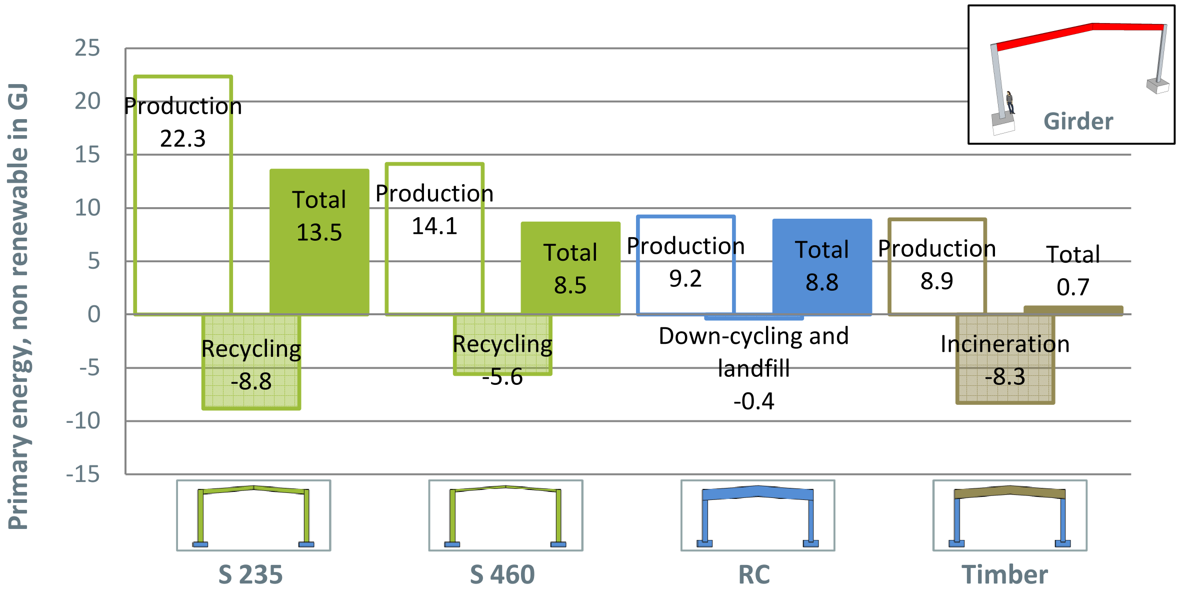
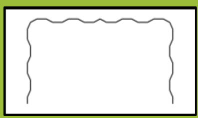


Figure 21: Total Primary Energy or the Product Stage (A1-A3) summed up with Benefits & Loads (D) from recycling (steel), incineration (timber) or rubble processing (concrete) for one girder, in GJ

8 | Building envelope

Compared are different possibilities for the building envelope of a otherwise identical single storey building: a not insulated "cold" building, three equivalently insulated "warm" buildings and a "super" building with high end insulation. In Table 7 the various building envelopes and their building physical properties are listed.

Table 7: Baseline data of the comparison of different building envelopes

	Cold building	**Warm building 1**	**Warm building 2**	**Warm building 3**	**Super building**
Symbol					
External walls	**Trapezoidal plates** (sheets), **cold** **U = 5.88**	**Steel-PUR-Sandwich panels,** **80 mm,** **U = 0.33**	**Aerated concrete,** **300 mm,** **U = 0.31**	**Cassette wall** (linear tray) **145+40 mm,** **U = 0.29**	**Steel-PUR-Sandwich panels,** **200 mm,** **U = 0.13**
Roof	**Trapezoidal plates, cold** **U = 7.14**	**Foil roof,** **140 mm MW,** **U = 0.28**	**Foil roof,** **140 mm MW,** **U = 0.28**	**Foil roof,** **140 mm MW,** **U = 0.28**	**Foil roof,** **320 mm MW,** **U = 0.12**
Skylight	2.4	2.4	2.4	2.4	2.4
Windows	1.3	1.3	1.3	1.3	1.3
Doors	4.0	4.0	4.0	4.0	4.0
Gates	2.9	2.9	2.9	2.9	2.9
Structural system	Pinned-base portal frame in steel grade S235				
Foundations	block foundations in concrete class C25/30				
Base plate	not insulated, U = 0.44				

MW = mineral wool

As can be seen in Figures 22 and 23 for the cold building the environmental data for Production Stage (A1-A3) summed up with Benefits & Loads (D, disposal or recycling) are the lowest. The equivalently insulated envelopes of the warm buildings show also balanced results. The super building with 200 mm polyurethane sandwich panels counts the highest value. But it is remarkable that the increase of Global Warming Potential and Total Primary Energy for the super building relatively moderate compared the increase of insulation, which is more than factor two. It is significant that by using sandwich elements, especially in comparison to the aerated concrete, a more eco-efficient insulation with also less panel thickness can be achieved.

For the next step the two polyurethane sandwich panel variants are scrutinized for the operational phase of the building. How long does it take for the super building to pay off for the higher Primary Energy demand producing the panels considering its lesser demand during operation?

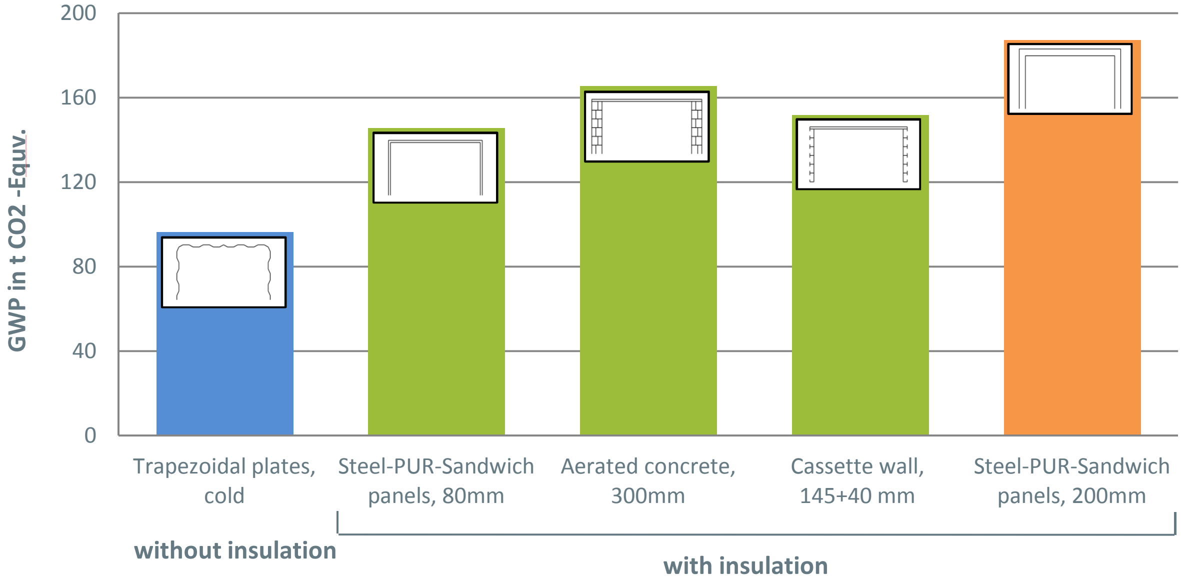


Figure 22: Global Warming Potential for Product Stage (A1-A3) summed up with Benefits & Loads (D) for external walls, in t CO2 Equivalent

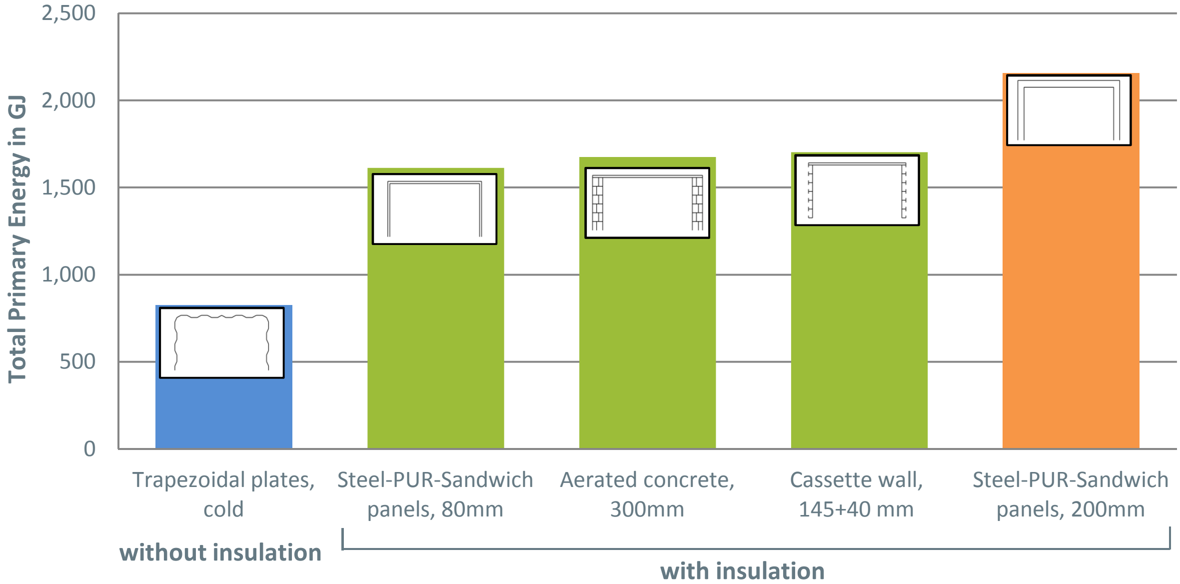


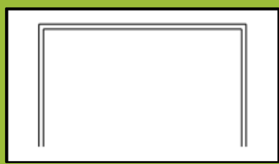
Figure 23: Total Primary Energy for Product Stage (A1-A3) summed up with Benefits & Loads (D) for of external walls, in t CO2 Equivalent

Comparison in the operational phase

The Total Primary Energy, which is required for the Product Stage (A1 –A3) and Benefits & Loads (D) of the building envelope (warm building 1 and super building, Figure 23), is converted from GJ to MWh (Table 8). Now the assumed average annual energy demand during the Use Stage (B6, Operational Energy Use, see also Figure 2) can be compared. In Table 8 those information are shown.

The assumed Annual Primary Energy demand can be summed up over time linearly, with a presumed utilization period of 20 years. Whereas the Total Primary Energy for Product Stage (A1 –A3) and Benefits & Loads (D) of the building envelope can be graphically displayed as an initial offset for simplicity, Figure 24.

Table 8: Primary Energy demand for warm building 1 and super building considering Product Stage (A1-A3), Benefit & Loads (D) and Operational Energy Use (B6)

	**Warm building 1** Steel-PUR-Sandwich panels, 80 mm 	**Super building** Steel-PUR-Sandwich panels, 200 mm 
Total Primary Energy for Product Stage (A1-A3) and Benefits & Loads (D)	**450 MWh**	**600 MWh**
Annual Primary Energy demand for Operational Energy Use (B6)	**111 MWh/a**	**90 MWh/a**

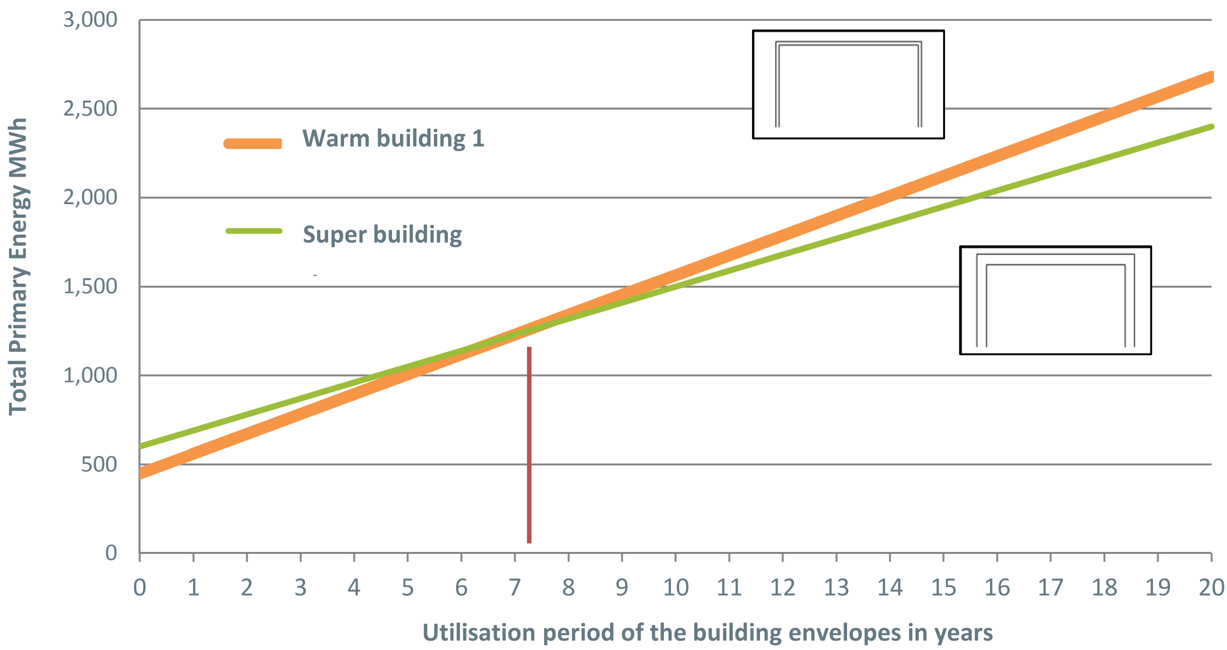


Figure 24: Comparison of Primary Energy demand for the building envelope of warm building 1 and super building over a utilization period of 20 years including Production Stage (A1-A3), Benefits & Loads (D) as well as Operational Energy Use (B6)

In terms of Primary Energy demand the super building pays off after about 7 years compared to the warm building 1, see Figure 24. The additional efforts for Product Stage (A1-A3) and Benefits & Loads (D) compared to a standard insulated building is compensated by the lower demand for Operational Energy (B6). Figure 25 illustrates this finding and makes the beginning of the real energy saving after about 7 years more obvious.

The comparison of building envelopes with different insulation properties shows the importance of considering the entire life cycle. Buildings are designed for a long period of use and so the decisions made during planning and construction may have long term consequences that must be considered. The comparison of the entire energy demand for a typical single story building with different building envelopes is only a simple example for demonstration purpose.

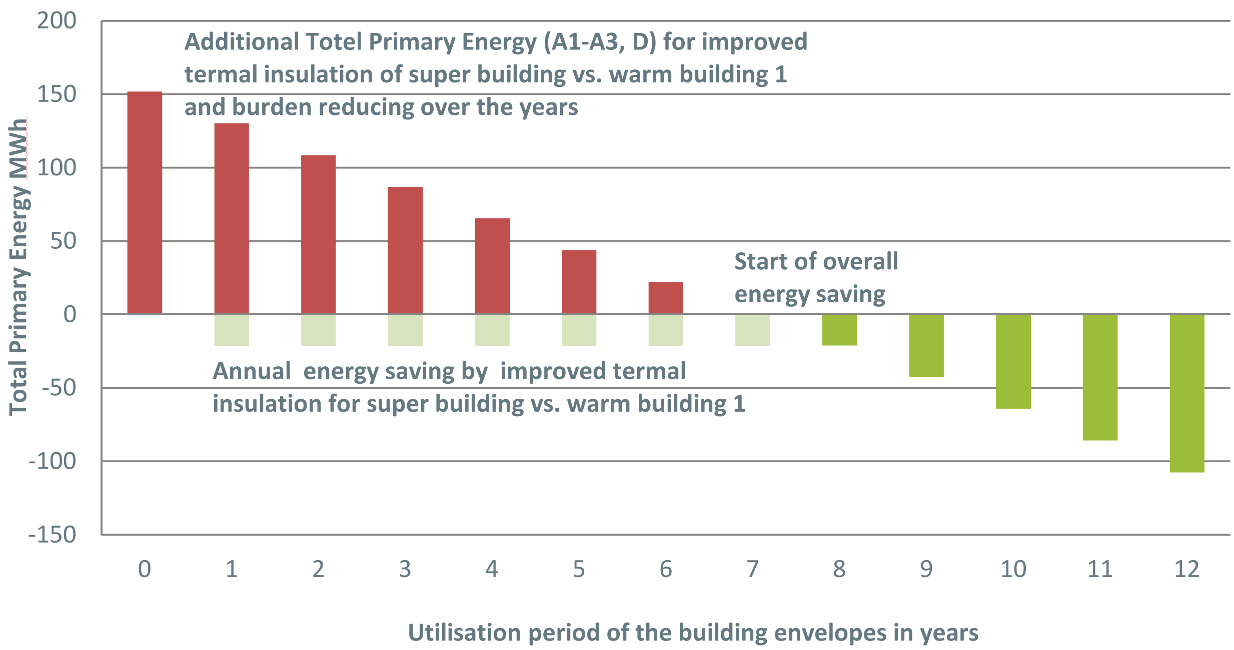


Figure 25: Amortisation of improved thermal insulation due to energy savings over the utilisation period

9 | Transport

Depending on the country where the steel has been produced (cradle to gate), additional environmental burden for transport must be considered (A4, Transport, see also Table 5). For structural steel produced (gate) in Western Europe, Brazil or China and used for construction in Western Europe (site) transport distances can be assumed as follows (Table 9):

Table 9: Average distances and means of transport gate to site for structural steel

	Ocean freight km	**Rail fright** km
Western Europe	**-**	**500**
Brasil	**10,000**	**500**
China	**20,000**	**800**

For the transport of one ton over a distance of 1 km (= 1 ton kilometer "tkm") in the Ökobau.dat environmental data are given as sown in Table 10. For simplicity packaging (containers etc.) are not considered.

A steel frame in S235 as described in Figure 2 and Table 2 is used for comparison of environmental effects of steel products including Transport (A4), see Figures 26, 27.

Table 10: Environmental data for ocean and rail fright according to Ökobau.dat 2009

	Global Warming Potential kg CO2/tkm	**Primary Energy Demand** MJ/tkm
Containership	**0.0145**	**0.1782**
Rail transport	**0.0286**	**0.5864**

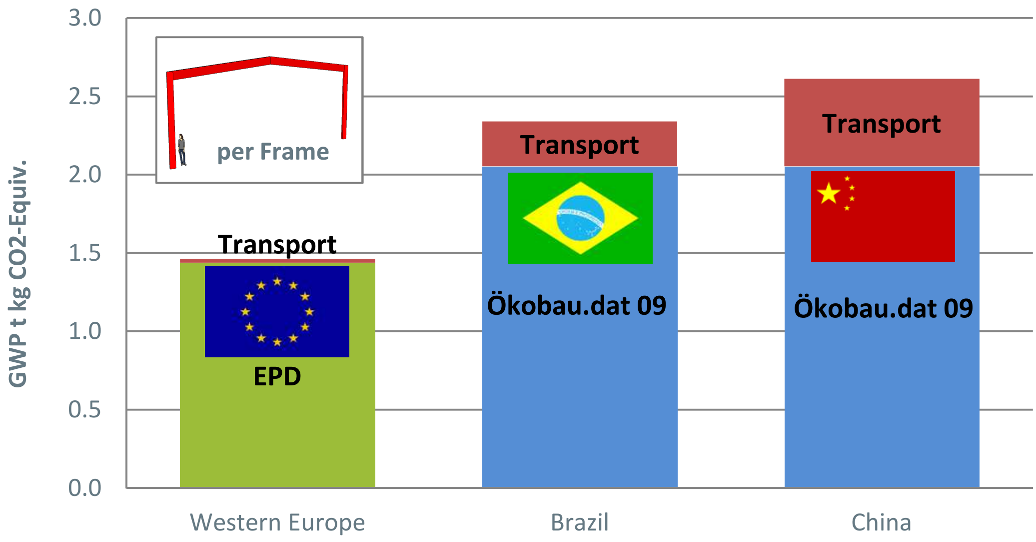


Figure 26: Global Warming Potential for a steel frame S235 including Transport (A4) from gate to site, in CO2 Equivalent

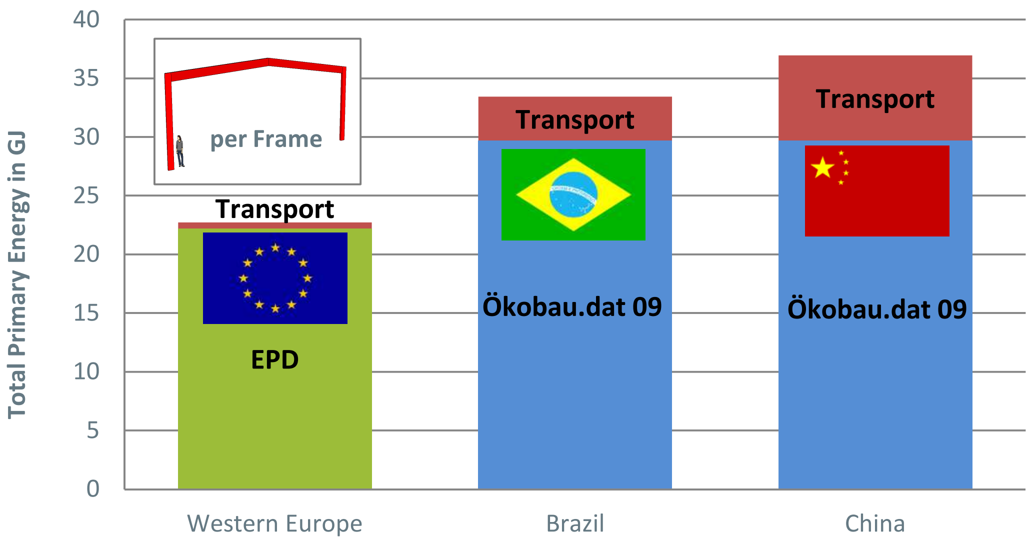


Figure 27: Total Primary Energy for a steel frame S235 including Transport (A4) from gate to site, in GJ

Compared with the calculated Primary Energy demand and Global Warming Potential per frame for Product Stage and Benefits & Loads long-distance transportation puts additional environmental burdens of up to 30% on the construction products (see Figures 26, 27). Through this significant proportion of the environmental data for long-distance transportation, it becomes clear that transport gate to site must be considered for a complete LCA of a building.

Steel and especially structural steel of high technical quality and favorable environmental characteristics is widely available in Europe. Taking into account the just described additional environmental burdens for transport, the superficial economic advantages of importing steel from far away regions are melting away if looked closer. Particularly structural steel from Western Europe, which is recycled over and over back into the industrial cycle, is therefore in fact a domestic construction material.

10 | Conclusions

With the comparison of the environmental performance of different structural systems and materials but same functionality it becomes evident, that the slim and material efficient design of steel structures is advantageous. It is not only the reduced material quantities for a certain structural element – here the frame of a single storey building – but also the reduced amount of columns, smaller foundations or less transports to the construction site etc.; the holistic view.

Another advantage of steel is its special "Cradle to Cradle" property: after the dismantling of a building structural steel can be directly reused or recycled thus be utilised as construction material again and saving natural resources and. By using high-strength steel, especially for tension and bending members, the life cycle assessment can be improved further. It became evident, that the level of comparison – e.g. material, member or functional unit - does have significant influence on the results. When a comparison of the environmental performance of construction materials is performed an example structure must be chosen, which can be found in practical construction and also covers typical load situations (compression, tension, bending). The holistic concept of Building Life Cycle Assessment requires that Benefits & Loads, which appear at the end of life of a construction material, to be considered. The comparison of construction materials at the required level of a functional unit showed that structural steel, especially those with Environmental Product Declaration, is considerably competitive. It must be mentioned again, that based only on environmental date per unit a direct comparison between construction products is meaningless. Depending on the specific situation or aim a complete functional unit – a structural system or some major members – must be compared.

The comparison of building envelopes with different thermal properties shows also the importance of considering beyond the production stage the entire life cycle. Buildings are usually designed for a long period of use. So the decisions made during the planning and construction phase may have far reaching consequences which shall be taken into account. The total energy demand based comparison of a typical single story building with various building envelopes is a plastic example for that.

Whilst short transport distances – e.g. the typical transport radius of 500 km in Europe – may be negligible, long distance transports do influence the LCA of construction products. Hence a complete LCA must also consider the transport from the factory gate to the construction site.

Efficient use of resources as well as reduction of waste are hot topics of the present political agendas and will soon be part of the European normative framework for the construction sector. As shown here, structural steel is well prepared to meet those goals.

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bauforumstahl
Deutscher Stahlbau. Gut beraten.

Sohnstraße 65 | 40237 Düsseldorf
Postfach 10 48 42 | 40039 Düsseldorf
T: +49 (0)211.6707.828 | F: +49 (0)211.6707.829
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