The Ecological Impact of Sieben Linden

Andrea Bocco, Martina Gerace, Susanna Pollini

DIST, Politecnico di Torino

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Dipartimento Interateneo di Scienze, Progetto e Politiche del Territorio

CONTENTS

0. Introduction

The present study was born out of an agreement between the Sieben Linden community (Siedlungsgenossenschaft Ökodorf e.G.) and the Politecnico di Torino (DIST), approved on May 9, 2013. The Politecnico team, led by professor Andrea Bocco, intended to perform an overall analysis of the way of living in the ecovillage, including a number of areas among which agriculture, biodiversity, building, decision-making, diet, economy, energy, land husbandry, etc. The Sieben Linden community, on the other hand, was particularly interested in having a new ecological impact assessment done, a dozen years after that by the University of Kassel.

Therefore, efforts were focussed on such topic, and data collection activities were developed under the coordination and continuous engagement of Sieben Linden's Christoph Strünke since then, both relying on existing databases and custom-crafting tools such as interviews and questionnaires. The final elaboration of data – which obviously showed that more details were still to be investigated or clarified – was prepared in 2016-17 by Martina Gerace and Susanna Pollini in the framework of their Master theses in Architecture at the Politecnico which was defended on September 26, 2017. A preview of the results had already been discussed with Sieben Linden community on March 3, 2017.

The methodology chosen is twofold:

a. the environmental impact of the ecovillage residents' lifestyle (that is, recurrent activities which are performed on an everyday basis) was assessed with reference to the Ecological Footprint (EF) method (see § 2), as it appeared an appropriate tool to produce an inclusive picture of the most relevant activities, and quantify them in a single unit of measurement, that is easy to visualise and communicate. Since the application of this method at the very large scale – that is, to a small entity such as a hundred-something community extending on a few ten hectares – has been tried quite seldom, it seemed to us a stimulating challenge to check its aptitude to describe even minute phenomena like those we were dealing with. The results obtained seem to confirm the appropriateness of the method to the task and their comparability with akin small-size human groups and ecovillages in particular, in spite of obvious simplifications (like for instance assuming that all areas are mono-functional), inability to describe phenomena not directly affecting ecosystems, and incomplete data libraries. These and other limitations implied by such method (see Bjørn *et al.* 2016, Castellani and Sala 2012) have become even more recognisable after the completion of this study. A much more complete, and correspondingly much more complex analysis would adopt other methods such as the 'absolute environmental sustainability' approach (Bjørn 2015, Njkær-Brejnrod *et al.* 2017).
b. the environmental impact of the construction of Sieben Linden buildings (that is, one-off activities aimed at creating items having an indeterminate 'service life') was assessed with

reference to two basic sustainability indicators (‘embodied energy’ or PEI and greenhouse gases emission or GWP: see § 3) and also ‘translated’ into EF terms (§ 4). Since no data could be collected regarding the energy expenditures at the building site, the service life is included in a. above, and no dismissal can be envisaged (or, at least, when and how it will happen), only the ‘cradle to gate’ phase was accounted for. Also in this case, we had to rely on not always complete and specific databases, and moreover we excluded recurring to proprietary databases and software; a complete LCA, although within the same boundaries, would have produced richer and more detailed information on the environmental impacts associated with building construction. In spite of such approximations, we believe that also in this field we were able to obtain satisfactory results which can be compared against similar case studies, and particularly so against other ‘green’ buildings.

Finally, the results obtained though the two methodologies have been merged (§ 5) and discussed (§ 6). The latter includes a few suggestions to contribute decreasing Sieben Linden’s impact on the environment, and mentions possibilities open to further research.

The present report was written having the Sieben Linden community in mind as the target audience and in view of the final presentation of November 23, 2017. Technicalities have been kept to a minimum (see Appendix for reference to scientific methodology) and therefore the report is adapted for circulation among the general public. Nevertheless, for the time being it must be understood for internal use only, as it cannot be circulated until two expected scientific articles are published.

Acknowledgements

Simone Contu introduced us to the EF methodology and gave us support in getting acquainted with its mathematics. Mathis Wackernagel of the Global Footprint Network agreed to furnish us with national datasets. Dirk Scharmer kindly provided technical information on the Libelle house. Chris West gave us support in accessing the EUREAPA database. Rajib Sinha of the Royal Technical University of Sweden and Morten Birkved of the Technical University of Denmark kindly reviewed the draft and provided suggestions on how to improve it.

Christoph Strünke was the guardian angel of this whole project and provided every kind of support from data collection to meetings organisation, and acted as the proactive linkage between the research team and Sieben Linden community. The list of people who kindly accepted to record their daily mobility or have an interview regarding lifestyle patterns would be too long to write down and would virtually cover most of the residents. However, a special mention should be made of Werner Dyck, Iris Kunze, Martin Stengel, Stella Veciana, and Michael Würfel for their specialist contributions.

1. Presentation of Sieben Linden and its spatial features

Sieben Linden (sometimes referred to as 7L) is an ecovillage and intentional community in the Altmark (Sachsen-Anhalt, Germany). Its aim is to realise a model of collaborative and holistic sustainable lifestyles, coupling a small ecological footprint with a high quality of life. Sieben Linden sees itself as an example and experiment in the development of an alternative and sustainable way of life, focusing on social and ecological aspects, such as a high degree of self-sufficiency and sustainable building practices. Sieben Linden is an active member of the GEN[1] and has engaged in an increasing number of cooperative activities and educational programs. Since its foundation in 1997, the area has increased from 25 to 82.5 hectares, including forest (47 hectares), gardens and farmland (28 hectares) and built-up areas (7 hectares). Currently (2017) about one hundred adults and forty children and teenagers live in thirteen houses and about fifty trailers. The total surface area – including community facilities – is 5,124 m^2. The number of residents is planned to grow up to 300.

[1] The Global Ecovillage Network (GEN) is a growing network of regenerative communities and initiatives that bridge cultures, countries, and continents. GEN builds bridges between policy-makers, governments, NGOs, academics, entrepreneurs, activists, community networks and ecologically-minded individuals across the globe in order to develop strategies for a global transition to resilient communities and cultures.
https://ecovillage.org/about/gen/ (Last accessed November 2017).

Plan of Sieben Linden
1:2000


Facilities
Residential houses
Trailers
Canopies

1.1 Orientation

Access to the ecovillage is via a dirt road that crosses it from west to east. Here narrower routes lead to its various areas and neighbourhoods. To the north, there are a parking and the joinery workshop, behind which lie the youth neighbourhood, the camping and the forest kindergarten. To the north extends the forest owned by the community. To the south of the entrance, there are a wide lawn, on which a guesthouse will soon be built, and Globolo – the area devoted to spirituality. Proceeding along the main road, one reaches the centre of the ecovillage: a former farmhouse where most communal facilities are found. A square, an amphitheatre and a pond surround this building complementing its functions. To the east of it, the residential neighbourhoods are located, and further to the southeast, the agricultural land.

1.2 Use of space

When the first settlers came to Sieben Linden they lived in trailers and shared outdoor facilities, as only a run-down farmhouse existed. The first interventions were focused on refurbishing it and transforming it into a community building: first the wing called Regiohaus (1998-1999) then the Nordriegel (2000-2002). During those early years there was a growth in the per capita availability of community space compared to residential space: this was due to the low number of residents and the absence of residential buildings. The amounts tended to coincide from 2001 to 2005, with the completion of the first residential buildings (Nordhaus and Südhaus) and the supply of new community spaces, such as Villa Strohbunt, the Strohballenkuppeln and the joiner’s workshop. Later the trend was reversed, as residential spaces began to grow more than facilities: the year 2005 marked the turn towards an expansion of the residential space. The total floor area per inhabitant grew from 34 m^2/person (1999), of which 21 community and 13 residential space, to 38 m^2/person (2016), including 11 community and 27 residential space.

Actually, the ecovillage's buildings are almost never made up of private apartments, but individual rooms and spaces shared between all tenants or a subgroup of these. The spaces of residential buildings were classified as: shared (accessible by all the inhabitants of the building and open to group use), individual (space for exclusive use of one inhabitant), and service spaces (circulation, storage, bathrooms, etc.). According to this classification the total residential area (3,754 m^2), can be broken down in 2,091 m^2 for individual use (including trailers), 812 m^2 for shared use and 851 m^2 for services. This translates into 15 m^2/person for individual use, 6 m^2/person shared and 6 m^2/person for services.

The residents' routine movements within Sieben Linden were investigated through interviews which produced information regarding eleven persons (8 adults and 3 minors). Although not statistically representative, these might help understand where inhabitants spend their time. Spaces were divided into 4 categories: own house, somebody else's house (within Sieben Linden), community spaces (including facilities and outdoor spaces), and outside Sieben Linden.

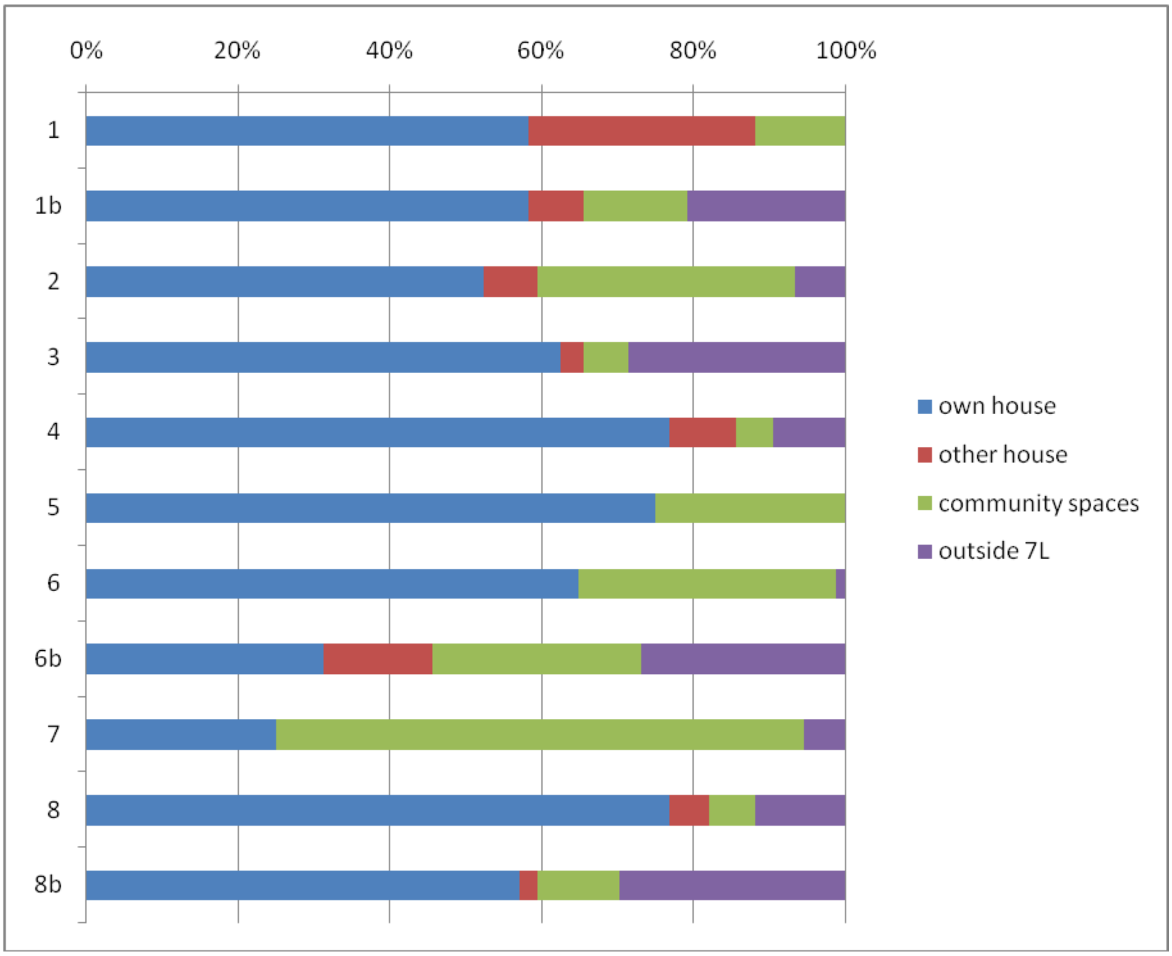
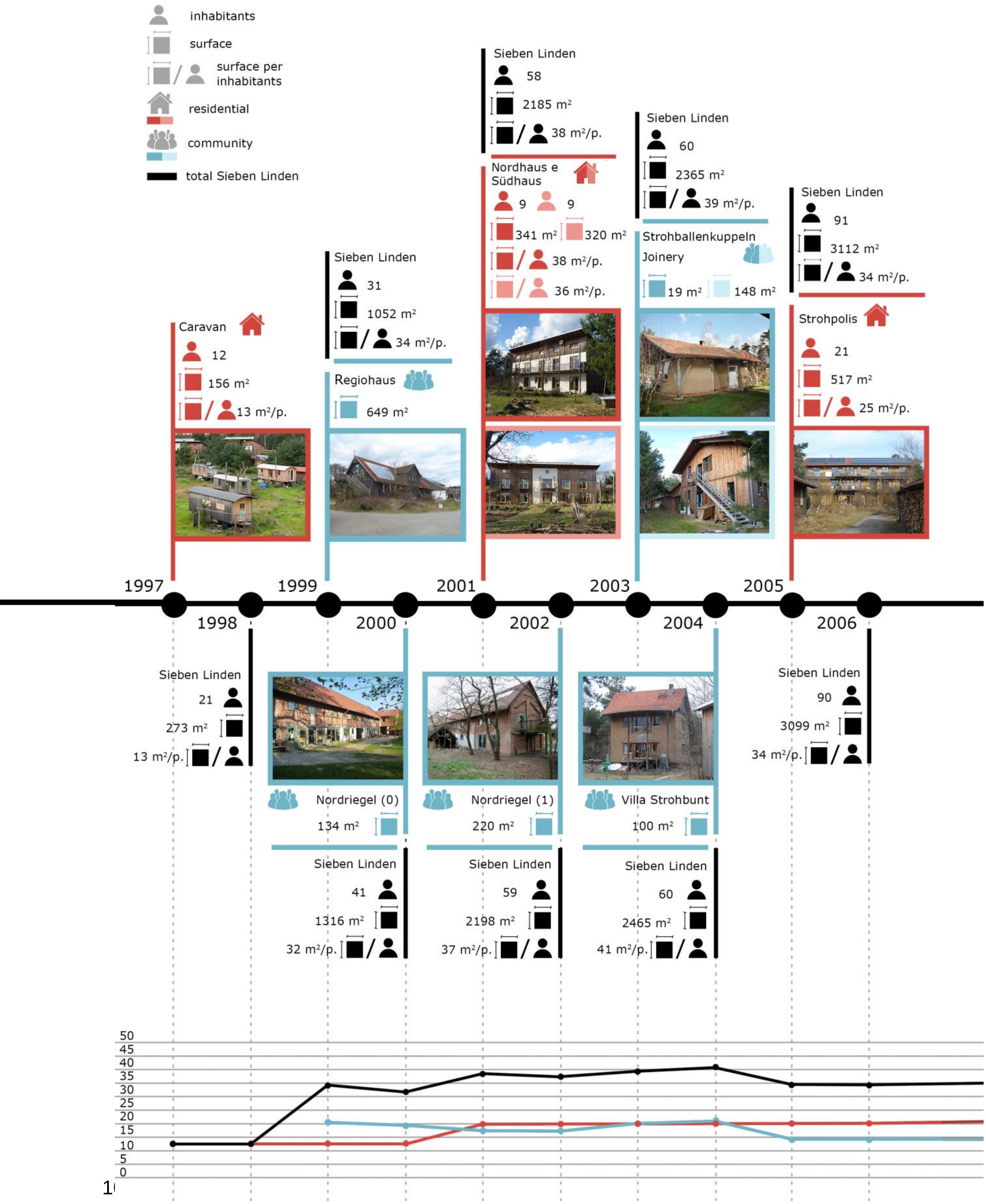
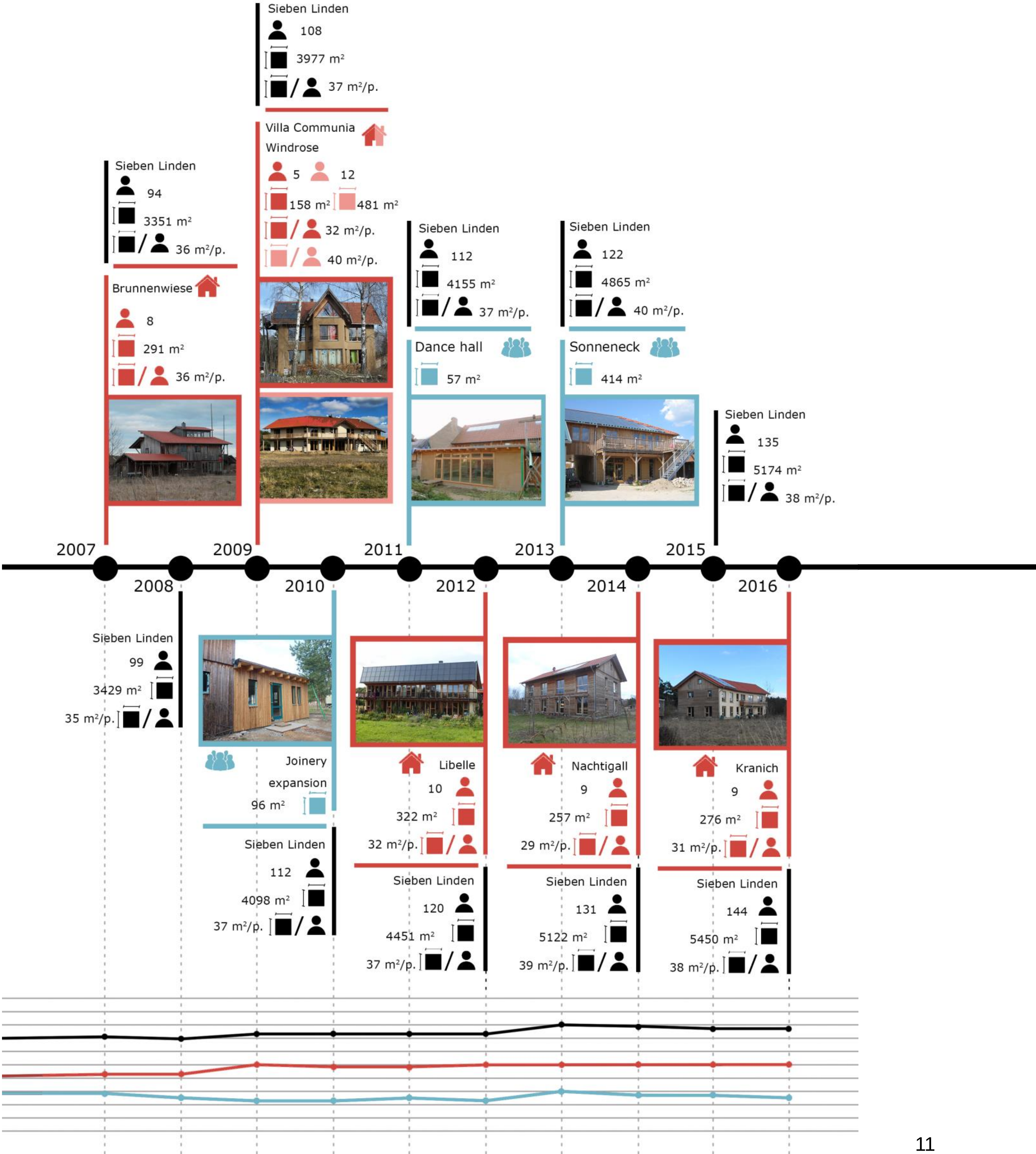


Figure 1: Share of time spent in different kinds of spaces

Figure 1 shows that interviewees spend most of their time at home (60%), while for the rest of the time they use the community spaces (20%) more than other homes (7%). Time spent outside is just 13%.

Below is the timeline of the evolution of the ecovillage's space from 1997 to 2016. The year 2017 was not included as it is still underway, and some buildings have yet to be completed.





Sieben Linden
108
3977 m²
37 m²/p.
Villa Communia
Windrose
5
12
158 m²
481 m²
32 m²/p.
40 m²/p.
Sieben Linden
94
3351 m²
36 m²/p.
Brunnenwiese
8
291 m²
36 m²/p.
Sieben Linden
112
4155 m²
37 m²/p.
Dance hall
57 m²
Sieben Linden
122
4865 m²
40 m²/p.
Sonneneck
414 m²
Sieben Linden
135
5174 m²
38 m²/p.
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
Sieben Linden
99
3429 m²
35 m²/p.
Joinery
expansion
96 m²
Sieben Linden
112
4098 m²
37 m²/p.
Libelle
10
322 m²
32 m²/p.
Sieben Linden
120
4451 m²
37 m²/p.
Nachtigall
9
257 m²
29 m²/p.
Sieben Linden
131
5122 m²
39 m²/p.
Kranich
9
276 m²
31 m²/p.
Sieben Linden
144
5450 m²
38 m²/p.

2. Ecological Footprint of Sieben Linden

The Ecological Footprint (EF) is a means of measuring the environmental impact. It expresses how much area of biologically productive land and water an individual, population or activity requires to produce all the resources they consume, and to absorb the waste they generate over one year time span, using ordinary technology and resource management practices.[2] By definition, the method accounts for energy and material flows on a yearly base, and does not include amortization accountancy of previously generated stocks: activities and material goods are only and wholly accounted in the year when they occur.

The EF tracks the use of six categories of productive surface areas: cropland, grazing land, fishing grounds (sea), built-up land, forest area, and carbon demand on land (energy land); only the use of renewable resources for which the planet has bioproductive capacity is accounted for. The EF, as it is measured using global average yields, is normalised by applying equivalence factors. These are multipliers which adjust different land and sea types according to their relative bioproductivity. (The equivalence factors are yearly updated by the Global Footprint Network (GFN)[3]; we used those published in the *National Footprint Account 2016*). The final result is expressed in conventional units called global hectares. EF can be compared to biocapacity (BC), which measures the bioproductive supply. The mathematical difference between BC and EF is called either reserve or deficit. For further information about the EF methodology see Appendix 1.

Conceived in 1990 by Mathis Wackernagel and William Rees at the University of British Columbia, the EF is now widely used by scientists, businesses, governments, individuals, and institutions working to monitor ecological resource use.

The EF method is applied to study of resource demand at a range of scales from the global and national scales down to much smaller scales such as region, city, household, or product. The EF of a city or nation is simply the sum total of the EF of all the residents of that city or nation. The methodology to calculate the EF and BC is published and regularly updated by the GFN.

There are two approaches to EF accounting: the compound and the component method. The main difference is that they draw upon different data sources to estimate the EF. The compound method estimates consumption based on national trade statistics and energy budgets (a 'top-down' approach). This methodology is used in the study of the EF of a country. The component method estimates consumption through analyses of material flows and activity components (a 'bottom-up' approach). The main sources of data for the component method are local investigations and life cycle studies; the quality of the analysis relies on access to significant databases of environmental information. (Lewan and Simmons 2001:12) The component method is frequently used in studies

[2] http://www.footprintnetwork.org/resources/glossary/ (Last accessed November 2017).

[3] Global Footprint Network is an international non-profit organization founded in 2003 to enable a sustainable future where all people have the opportunity to thrive within the means of one planet. https://www.footprintnetwork.org/about-us/ (Last accessed November 2017).

of sub-national areas. This method is not yet standardised and the results of different studies vary so much to the extent that they cannot easily compare. A template method should be developed, as it is suggested in the report presented at the Workshop on Ecological Footprints of sub-national geographical areas held in Oslo between 23rd and 25th August 2012 (Lewan and Simmons 2001). This study follows the component method; Table 1 shows the variables used.

component	variable	unit of measurement
energy	electricity	kWh
	firewood	stacked m^3
	solar panels	kWh
	propane gas	kg
items	non-food products	pcs
	wood products	pcs
waste	recycled paper	m^3
	recycled metal	m^3
	recycled plastic	m^3
	recycled electronics	m^3
	mixed waste (incinerator)	m^3
travel	travel by car	km/person
	travel by bus	km/person
	travel by urban public transportation	km/person
	travel by air plane	km/person
	travel by ship	km/person
food	food	kg
other	built-up land	m^2
	services	-

Table 1: Components and variables used in this study

2.1 Boundaries of study and functional units

A fundamental question is whether the aim of the study is to assess the footprint of the ecovillage or its community. The first approach (geographical approach) just considers the activities carried out inside the physical boundary of the ecovillage; the second (responsibility principle) accounts for the consumption of the ecovillage’s residents, independently of its physical boundaries. In the present study, the latter approach has been adopted.

The functional unit is the consumption of resources (energy and materials) and the production of waste of Sieben Linden community in 2014 (base year), considered as a whole and without distinctions according to age, status, gender or other categories. At that time, 130 people lived in the ecovillage (98 adults, 32 minors); this figure includes full members, people in trial year, long-term volunteers and private guests. Three residents (adults) left the ecovillage during that year; they are not considered in the study.

2.2 Data collection and revision

Data were derived from a variety of sources. The ecovillage provided detailed information about the community's consumption and waste production over the base year (or a one-year period, between 2014 and 2015). Data not covered otherwise were collected through interviews.

Sieben Linden runs several seminars every year. These attract people who stay for a few days or even weeks. Data for energy, waste and food components cannot but include both residents and guests. To exclude the guests' share from the EF assessment, their consumption was calculated on the basis of the number of nights spent in the ecovillage.

On the other hand, data for energy, waste and food only refer to the consumption of residents within the ecovillage. On average, residents spent 273 days per year in Sieben Linden. The average annual consumptions has been calculated by multiplying the daily consumptions by 365. This might imply some underestimation as 1) it is possible that lifestyle patterns are not as virtuous outside the village as they can be in the village; 2) minors, who must have a slightly lower EF, show a tendency to spend more days (300) in the village than adults (264).

2.3 Ecological footprint calculations

2.3.1 Energy

This section includes household energy consumption from electricity, heating and cooking. Data on electricity consumption were derived from meter readings; the ecovillage only uses 'green electricity' 100% derived from renewable sources (EO.N-Ökostromprodukte and on site PV panels). Firewood is used for space and water heating; data on firewood consumption were provided by the ecovillage. Sanitary water is also heated by solar panels, which produce about 600 kWh/person, Data on propane gas consumption (for cooking) are derived from bills. Information on firewood and propane consumption was provided in different units and converted in kWh using the calorific value of each fuel. Table 2 and Fig. 2 show a breakdown of the energy footprint.

energy type	consumption [kWh/person]	EF [gha/person]		
		energy land	forest land	total
electricity:				
PV panels	294	0.000	0.000	0.000
EO.N	257	0.000	0.000	0.000
heating:				
firewood	3,211	0.000	0.558	0.558
solar panels	600	0.006	0.000	0.006
propane gas	231	0.013	0.000	0.013

total	4,593	0.019	0.558	0.577

Table 2: Energy consumption and footprint

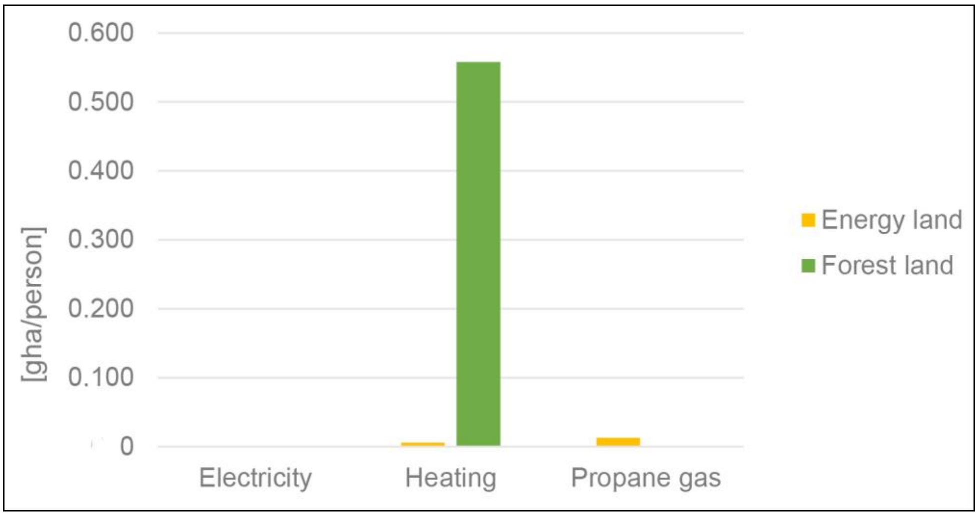


Figure 2: Energy footprint

Total energy footprint is 0.576 gha/person. Firewood is the greatest contributor to the footprint, that is more than 96% of energy footprint (see Table 2 and Fig. 2). This is due to the extension of forest needed to produce firewood. (As it is typical of this method, EF tends to emphasise the impacts connected to biotic productions.) In 2014 the ecovillage only burnt firewood obtained from its own forest; the forest is managed sustainably and no more firewood is extracted than the forest's annual growth. The energy land component of heating EF is due to the impact of on-site solar panels installed in 2014 (data were extrapolated from Menzies and Roderick 2010).

Electricity has no impact: the impact of on-site PV panels has not been accounted as no new one has been installed in 2014; electricity purchased from the power grid has been assessed as zero impact as it is 100% generated from renewable sources, while power stations and transmission infrastructure are accounted in the services (see § 2.3.7).

2.3.2 Goods

Data for the goods category were available for a selection of durable products (vehicles, office equipment, home appliances) and non-durable products (clothes, books, magazines, newspapers). The first were derived from an inventory of all such items existing in Sieben Linden; in accordance to Ecological Footprint methodology, only new items bought in 2014 were accounted in the study. Data on non-durable products were based on interviews, which for instance revealed an average acquisition of 8 new garments, 7 new books, and 15 magazines per year and per capita, and 0.2 newspapers per day and per capita.

0.8 mobile telephones are possessed per capita (50% are smartphones), in spite of the prohibition of making use of them within the ecovillage. On average, Sieben Linden residents spend 5 hours on the Internet per capita and per day. Table 3 shows a review of items possession and acquisition in Sieben Linden from 1996 to 2016.

item	total amount (2016)	amount per capita (2016)	acquisition rate* per year (average)	acquisition rate* per capita	average age [yrs.]
cars	34	0.26	1/2	0.004	12
fridges	32	0.25	2	0.015	7
freezers	10	0.08	1/3	0.002	13
dishwashers	5	0.04	1/5	0.002	8
washing machines	9	0.07	1/5	0.002	10
laptops	97	0.75	4	0.032	5
PCs	7	0.05	1	0.002	4
printers	39	0.30	2	0.018	5
TVs	12	0.09	1	0.009	4

** new items only*

Table 3: Items possession and acquisition

Table 4 and Fig. 3 show a breakdown of the goods' footprint.

goods	new items per year per person (2014)	EF [gha/person]			
		energy land	cropland	forest land	total
office equipment and home appliances	0.11	0.005	0.000	0.000	0.005
vehicles	0.01	0.001	0.000	0.000	0.001
books, magazines and newspapers	95.00	0.006	0.000	0.031	0.037
clothes	8.00	0.012	0.012	0.000	0.024
total	103.12	0.024	0.012	0.031	0.067

Table 4: Goods footprint

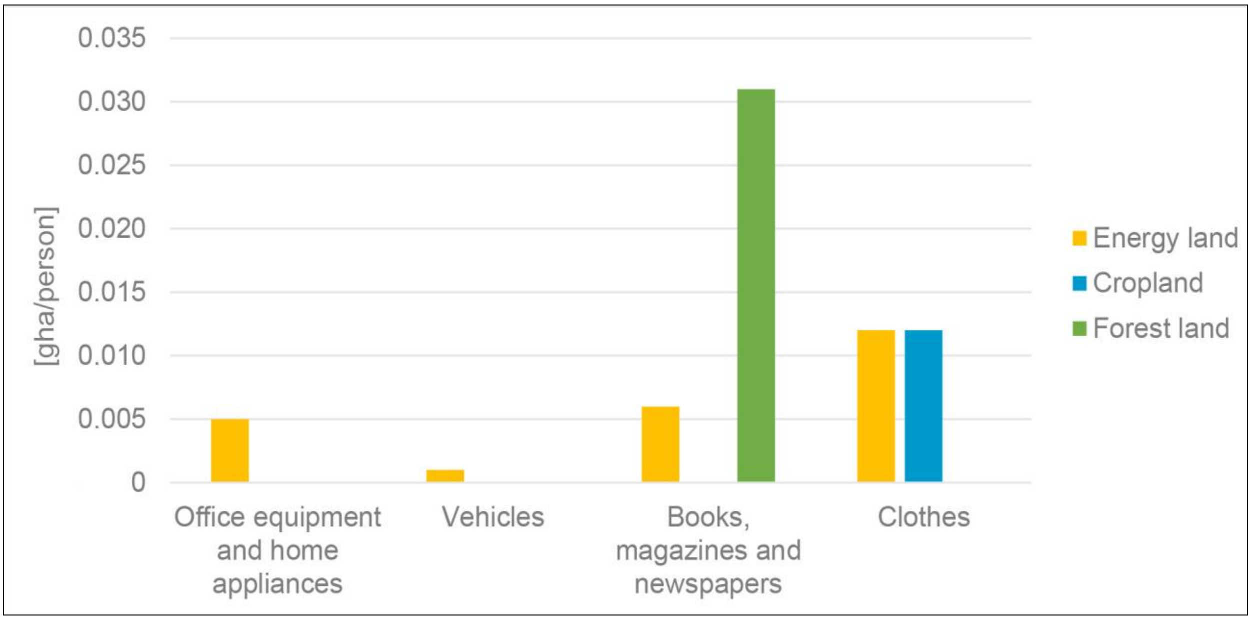


Figure 3: Goods footprint

Goods footprint is 0.067 gha/person. This includes both durable and non-durable items. Non-durable goods are the greatest contributors to the footprint. This is due to the large number of consumables purchased in one year (see Table 4). Vehicle footprint is very small thanks to the low number of new vehicles purchased (see Table 3 and 4): most cars are second hand, and the number of cars per person is lower than 0.3 (the German average is 0.572).[4]

2.3.3 Waste

Waste production is yearly monitored by the ecovillage, which provided data on the main categories of recyclable waste as well as mixed waste. Glass waste was not accounted because of the lack of information. Waste production in the ecovillage, which is 101 kg per person (excluding glass and organic waste), is noticeably lower than German average (German average municipal waste generated in 2015 was 625 kg/person).[5] Organic waste is treated in an on-site treatment plant. Therefore, it is not accounted in the EF calculation. Table 5 and Fig. 4 show a breakdown of waste footprint.

waste	weight [kg/person]	EF [gha/person]
paper (recycle plant)	51	0.007
plastic (recycle plant)	12	0.001
electronics (recycle plant)	1	0.000
metals (recycle plant)	1	0.000
mixed waste (incinerator)	36	0.017

[4] http://www.nationmaster.com/country-info/stats/Transport/Road/Motor-vehicles-per-1000-people (Last accessed November 2017).

[5] http://ec.europa.eu/eurostat/statistics-explained/index.php/Municipal_waste_statistics (Last accessed November 2017).

total	101	0.026

Table 5: Waste footprint

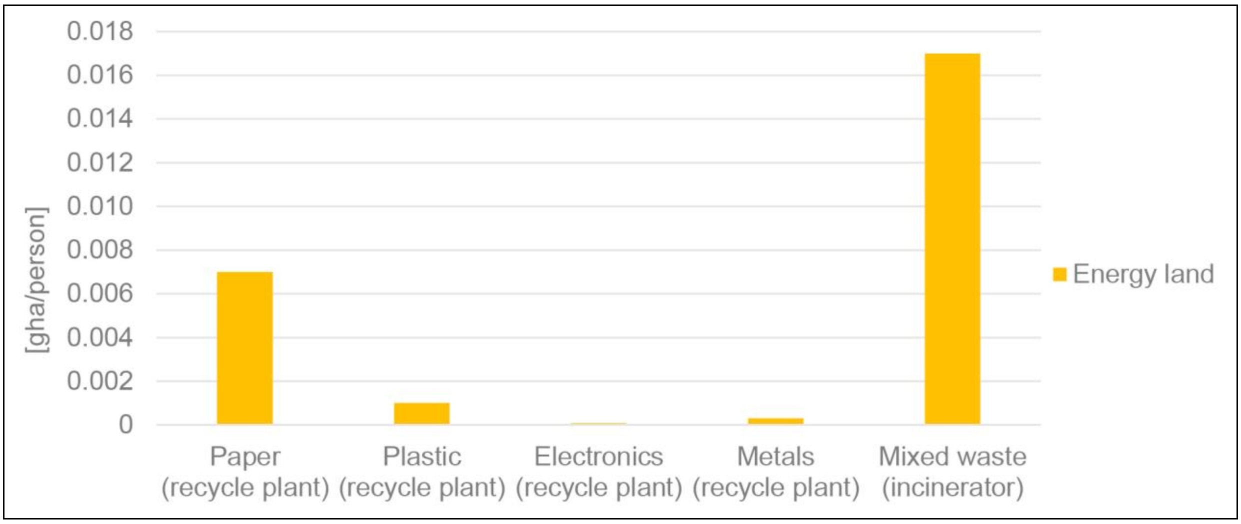


Figure 4: Waste footprint

Waste footprint is 0.026 gha/person. This only includes energy land needed to absorb CO_2 emissions generated by treating waste. The impact of the plant itself (construction and maintenance) is not accounted as it is accounted in the services (see § 2.3.7). Mixed waste represents more than 65% of total waste footprint. Paper, which constitutes the largest share by weight, contributes to EF by 25% only (see Table 5 and Fig. 4).

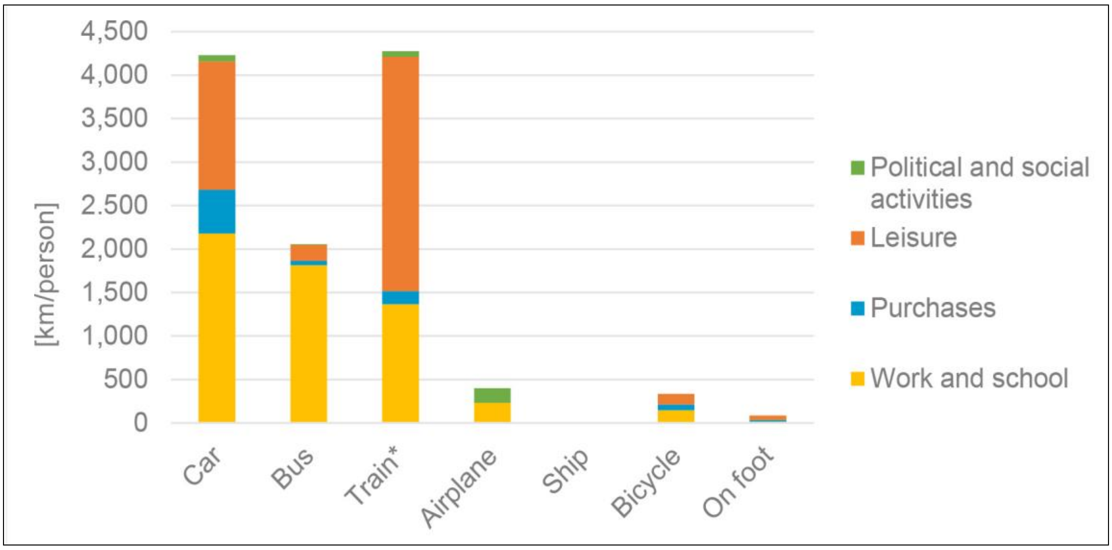
2.3.4 Travel

Between June 2014 and May 2015, 24 residents (19 adults and 5 children or teenagers, that is, 20% of the community) took part in a program to monitor travel outside the village (circulation of motor vehicles inside the ecovillage is prohibited); furthermore, an estimation on travel attitudes of each resident has been supplied by the ecovillage. Combining this information, the distances travelled per resident have been calculated. Information about airplane travel was given separately for all residents. Table 6 and Fig. 5 show a breakdown of kilometres per person travelled outside the ecovillage, by purpose and means of transport.

reason of travel	person kilometres [km/person]							
	car	bus	train*	airplane	ship	bicycle	on foot	total
work and school	2,180	1,815	1,366	231	0	145	15	5,753
purchases	500	51	151	0	0	66	21	788
leisure	1,478	183	2,693	0	2	123	48	4,527
political and social activities	70	6	65	169	0	0	0	311
total	4,228	2,054	4,276	400	2	335	85	11,417

**includes tramway, underground*

Table 6: Breakdown of travel by purpose and means of transport



*includes tramway, underground

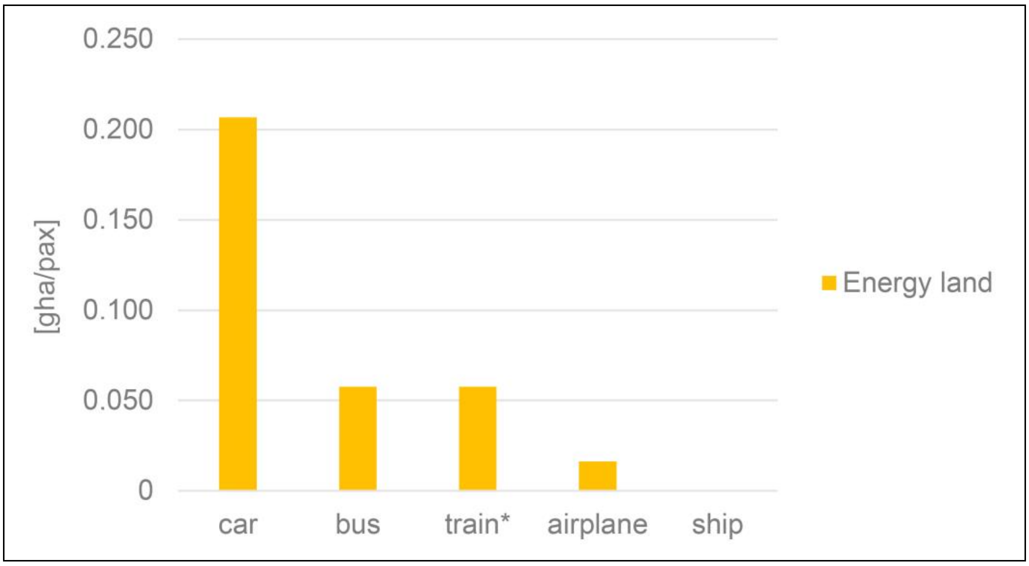
Figure 5: Breakdown of travel by purpose and means of transport

Travel footprint only accounts for the energy land needed to absorb CO_2 emissions generated by motor vehicles. Walking and cycling have not been included in the footprint, as they have no emissions. A separate survey regarding daily movement routines inside the ecovillage (see § 1.2), which sampled 11 residents, showed that on average more than 1 km is walked every day per person, which makes about 293 km per person per year. These would bring the total distance travelled per year to 11,709 km, of which walking and bicycling are about 6%, public transport 54%, air travel 3%, and private motor transport 36%. EF of infrastructure construction and maintenance are accounted in the service footprint (see § 2.3.7). Table 7 and Fig. 6 show a breakdown of the travel footprint.

means of transport	person kilometres [km/person]	EF [gha/person]
car	4,228	0.207
bus	2,054	0.058
train*	4,278	0.058
airplane	400	0.016
ship	2	0.000
total	10,997	0.338

*includes tramway, underground

Table 7: Travel footprint



**includes tramway, underground*

Figure 6: Travel footprint

Travel footprint is 0.338 gha/person. Travel footprint is dominated by car travel (61%). Bus and train have the same impact but distances travelled by train are double than those by bus (see Table 7 and Fig. 6).

2.3.5 Food

Food data were provided by the ecovillage, based quantities handled by the food cooperative (which provides food for the community kitchen in the Regiohaus and for the residents' home consumption) and sold by the local shop (here, one can buy special foods such as meat and chocolate). The cooperative also provides self-produced vegetables and fruits, which are grown biologically and without machinery. Most residents are vegetarian or vegan; the community kitchen only serves vegetarian and vegan meals. Meat consumption in Sieben Linden is 97% lower than German average; while dairy products consumption is 10% lower.[6] However, the amount of food consumed by Sieben Linden residents – even when they are in the ecovillage – is somewhat underestimated (and therefore the food EF) as some residents happen to buy some of their foodstuff outside the village, or occasionally have pizza delivered to their homes. Table 8 and Fig. 7 show the main categories that contribute to the food footprint.

food type	weight [kg/person]	EF [gha/person]				
		energy land	cropland	grazing land	sea	total
vegetables, fruits	489	0.081	0.128	0.000	0.000	0.208
cereals, bread, pasta	93	0.025	0.105	0.000	0.000	0.130
oils, spices	20	0.007	0.070	0.000	0.000	0.077

[6] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4462161/ (Last accessed November 2017).

beverages	152	0.030	0.039	0.000	0.000	0.069
meat, fish, dairy products	92	0.035	0.000	0.110	0.004	0.149
sweets and other	76	0.007	0.081	0.000	0.000	0.088
total	923	0.186	0.422	0.110	0.004	0.722

Table 8: Food footprint

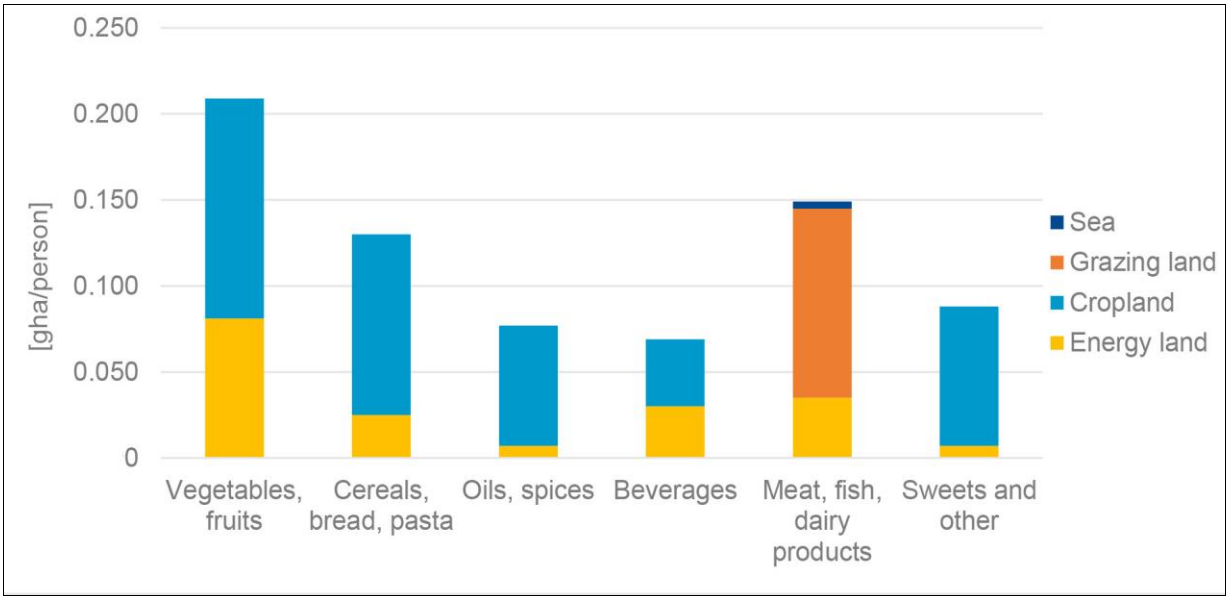


Figure 7: Food footprint

The food footprint is 0.722 gha/person. This includes both transport and production of food. Nevertheless, transport accounts for less than 5% due to the residents' preference for local products (74% of total food purchase is from Germany and less than 5% is non-European). Table 8 shows a breakdown of food footprint compared to a breakdown of food consumption by weight.

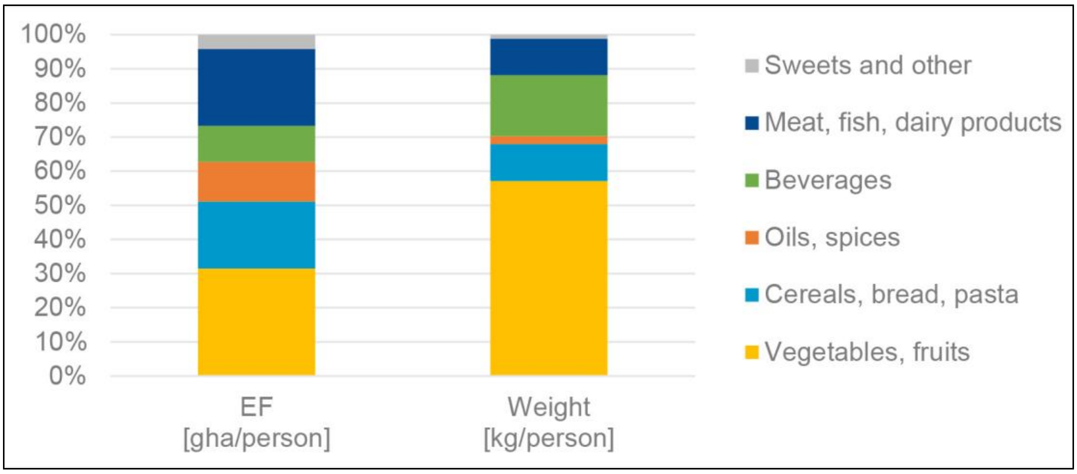


Figure 8: Comparison between food footprint and food weight

Vegetables and cereals are the largest contributors to the food footprint (see Table 8 and Fig. 7). This is mainly related to the area required to grow them. However, vegetables and cereals are characterized by a lower unitary footprint than dairy products (see Fig. 8). Vegetables account for more than 50% of total consumption by weight, whereas their footprint is less than 30% of total footprint. Meat and dairy products are little consumed but imply a high footprint (20%).

2.3.6 Built-up land

Built-up land reflects the bioproductive area compromised by anthropic infrastructure. Built-up land information for the ecovillage has been extracted from plans and technical drawings. This includes the area occupied by residential and communal buildings, trailers and roads. Thanks to the community's lifestyle privileging the use of collective space, the buildings do not take much land. Furthermore, most 'roads' are in fact just paths. Table 9 and Fig. 9 show built-up land footprint.

	built up land [ha/person]	EF [gha/person]
buildings	0.004	0.009
trailers	0.001	0.002
roads	0.009	0.022
total	0.013	0.034

Table 9: Built up land footprint

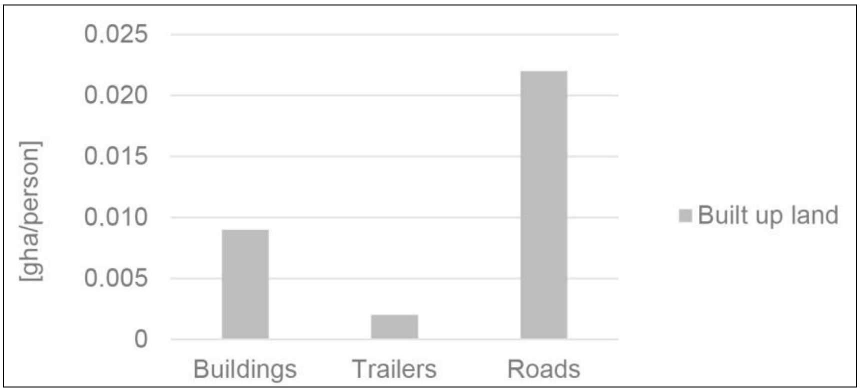


Figure 9: Built up land footprint

Built up land footprint is 0.034 gha/person.

2.3.7 Services

Data on services have not been collected for the ecovillage as it would be impossible to calculate them; national average data were used instead[7]. According to EUREAPA, the contribution of services to the EF for German citizens is 1.32 gha/person. This includes government services (i.e. health, education) and capital investment (i.e. infrastructure).

2.3.8 Overall footprint

The total EF for Sieben Linden residents is 3.08 gha/person; the footprint of the whole ecovillage is

[7] https://www.eureapa.net/explore/?impactgroup_id=1&region_id=9&footprintgroup_id=0 (Last accessed November 2017).

391.67 gha. Table 10 and Fig. 10 show a breakdown of the categories contributing to the footprint.

components		EF [gha/person]							%
		energy land	cropland	grazing land	forest land	sea	built-up land	total	
energy	electricity	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00
	heating	0.006	0.000	0.000	0.558	0.000	0.000	0.564	18.31
	propane gas	0.013	0.000	0.000	0.000	0.000	0.000	0.013	0.42
goods	items	0.024	0.012	0.000	0.027	0.000	0.000	0.067	2.05
waste	waste	0.026	0.000	0.000	0.000	0.000	0.000	0.026	0.84
travel	travel	0.338	0.000	0.000	0.000	0.000	0.000	0.338	10.97
food	food	0.186	0.422	0.110	0.000	0.004	0.000	0.722	23.44
other	built-up land	0.000	0.000	0.000	0.000	0.000	0.034	0.034	1.10
	services	-	-	-	-	-	-	1.320	42.86
total		0.592	0.434	0.110	0.584	0.004	0.034	3.080	100.00

Table 10: Overall footprint

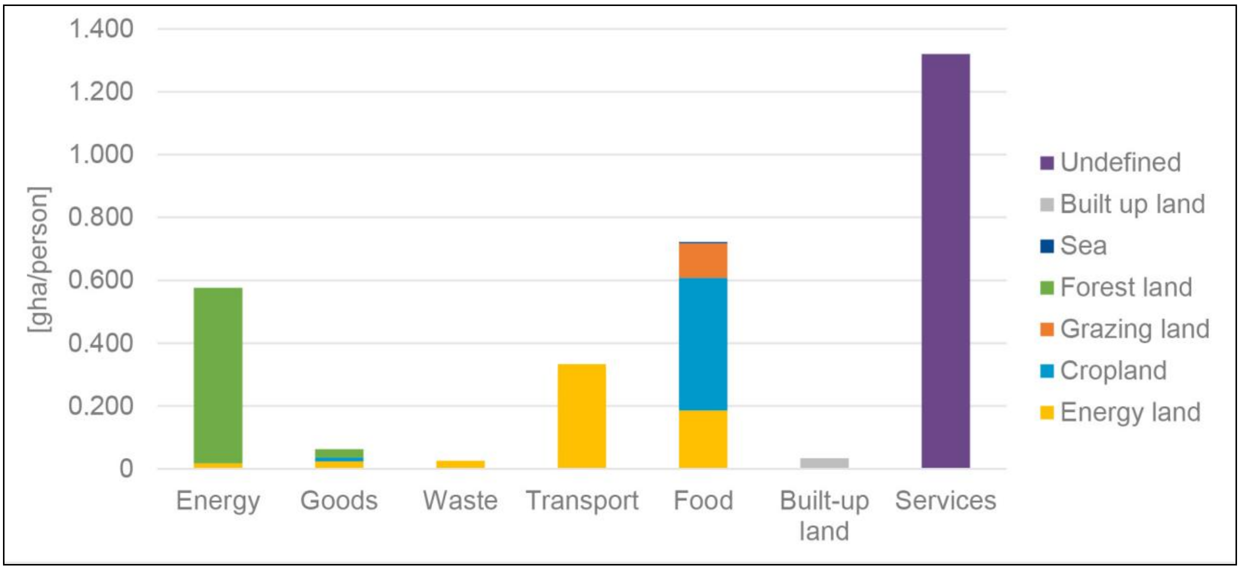


Figure 10: Overall footprint

The EF is dominated by the impact of services, which represents 43% of total footprint. This part is ascribed to Sieben Linden residents as German citizens and cannot be directly influenced by their lifestyle choices. Excluding services footprint, the residents' footprint is 1.76 gha/person. The greatest contributor to the locally-controlled part of the footprint is food (41%), mainly because of the large extent of cropland needed to grow vegetables and cereals. Energy footprint is 33%, mostly forest for firewood production. Transport footprint is less than 20% and is mainly due to the use of cars (the nearest operating train station is 30 km away). Waste, goods and built-up land footprint don't affect much the overall footprint and together represent less than 7% of total footprint.

2.4 Comparisons

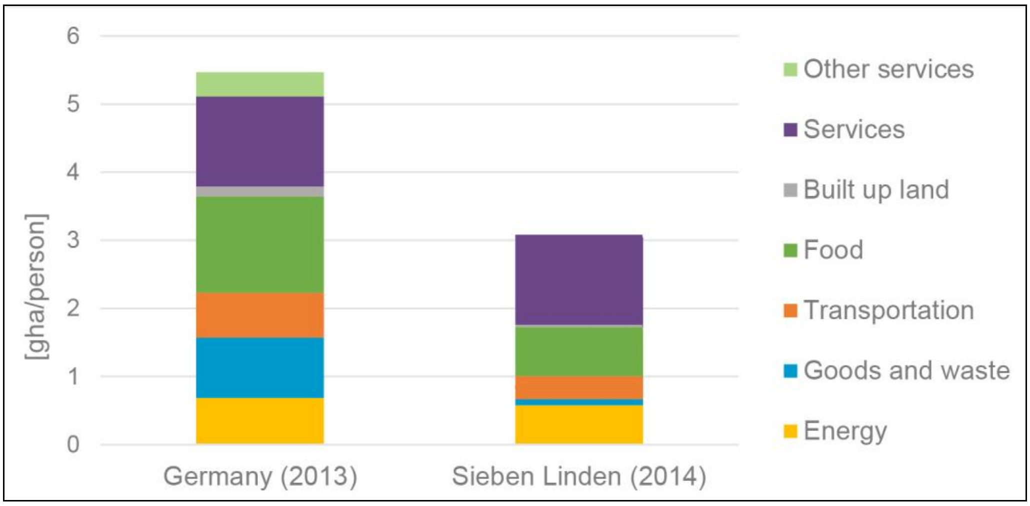
2.4.1 Sieben Linden vs. German average

Table 11 and Fig. 11 show the ecological footprint of Sieben Linden residents compared to the average German citizen. Data on German footprint are available through the Global Footprint Network open data platform; [8] these data have been subdivided according to EUREAPA categories.[9]

category	Germany (2013)		Sieben Linden (2014)	
	EF [gha/person]	%	EF [gha/person]	%
energy	0.684	12.5	0.577	18.7
goods and waste	0.886	16.2	0.089	2.9
travel	0.658	12.0	0.338	11.0
food	1.413	25.8	0.722	23.4
built up land	0.149	2.7	0.034	1.1
services	1.320	24.1	1.320	42.9
other services*	0.360	6.6	-	-
total	5.470	100.0	3.080	100.0

** includes communication, leisure, tourist facilities, etc.*

Table 11: Comparison between Sieben Linden footprint and average German footprint



[8] http://data.footprintnetwork.org/#/analyzeTrends?type=EFCtot&cn=79 (Last accessed November 2017).

[9] https://www.eureapa.net/explore/?impactgroup_id=1&region_id=9&footprintgroup_id=0 (Last accessed November 2017).

Figure 11: Comparison between Sieben Linden footprint and German average footprint

As the national average values do not include a heading for waste – possibly because associated with the category of products that generate it – the impact of waste produced by ecovillage residents has been summed to that of goods. Values for services are by definition the same as we applied the national average for Sieben Linden as well; whereas we were not able to assess the impact of 'other services' (which includes communication, leisure, tourist facilities, etc.) for Sieben Linden, and we left it blank.

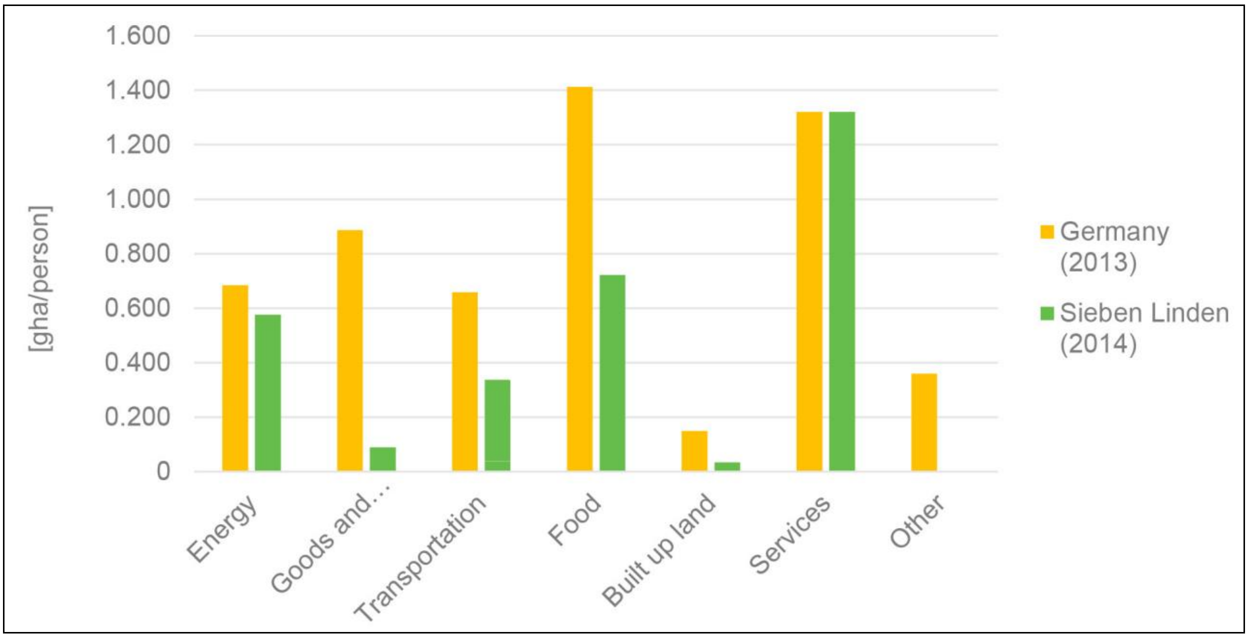


Figure 12: Breakdown of Sieben Linden footprint and German average footprint

The ecovillage's impact of energy is slightly lower than the German average – yet it is relevant to underline that most of such impact is due to the exploitation of a renewable resource (firewood), while that of Germany is mainly due to CO_2 emissions from the burning of non-renewable fuels. In all the remainder categories Sieben Linden fares significantly better than the average. Goods and waste are almost 90% lower, probably thanks to the frugal buying patterns coupled with sharing and exchanging second-hand items. In both travel and food categories the ecovillage's EF is approximately one half of the national mean. In sum, the overall EF of Sieben Linden is 56% of the German average (see Table 11 and Fig. 11).

2.4.2 Sieben Linden vs. fair share ecological footprint

The Ecological Footprint of every individual and every country can be expressed in the number of Earths ('Planet Equivalent') it would take to support that Footprint if everyone lived like that individual or the average citizen of that country; it is the ratio of the EF to the per capita biological capacity available on Earth.[10] Such capacity was 1.7 gha in 2013.[11] The Vales (2013) defined this as the 'fair share' ecological footprint.

Excluding services footprint, we calculated Sieben Linden residents' footprint at 1.76 gha/person in 2014 (see Table 10). This would almost equal the 'fair share' EF. However, as we add the impact of services, the overall footprint grows to 3.08 gha/person, which means 1.8 Planet Equivalents (see Fig. 13). In 2013, the world average Ecological Footprint of 2.87 gha was 1.7 Planet Equivalents.

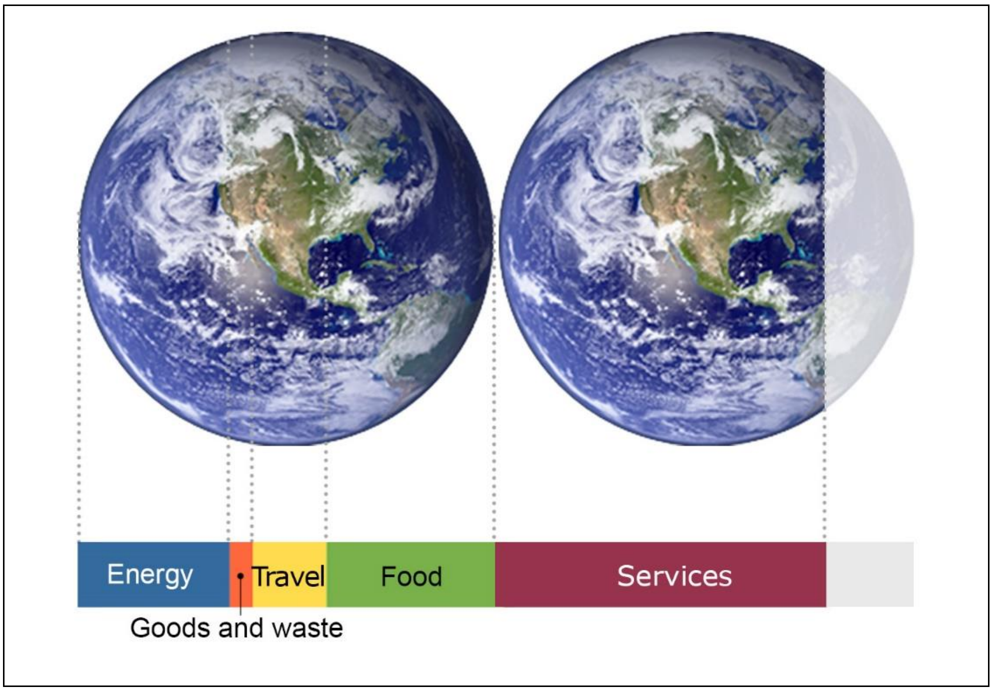


Figure 13: Planet Equivalents for Sieben Linden

2.4.3 Sieben Linden vs. other ecovillages

The results obtained have been compared against six selected cases:

- BedZED (*BedZED* 2009);
- the Findhorn Foundation and Community (Tinsley and George 2006);
- Steward Community Woodland (Knight 2008);
- Toarp ecovillage (Haraldsson and Svensson 2000);
- Krishna Valley (Lánczi 2009);
- OUR Ecovillage (Giratalla 2004).

These cases were chosen according to two criteria:

- affinity: cases showing environmental and social similarities with Sieben Linden. Selected cases are located in contexts that are comparable with Sieben Linden, both climatically and socio-economically (Europe, UK, Canada). Moreover, all communities are based on

[10] https://www.footprintnetwork.org/resources/glossary/ (Last accessed November 2017).

[11] http://data.footprintnetwork.org/#/compareCountries?type=BCtot&cn=5001&yr (Last accessed November 2017).

sustainability principles, which affect the ways of everyday life.

- availability: clear explanation of methodology, completeness of survey.

The methodological consistency has been checked against the 14 compatibility criteria identified by Lewan and Creig (2001). The main discrepancies include the lack of data for ‘goods’ (2 cases), waste (4 cases) and built-up land (5 cases).

We decided to keep the impact due to public services out of the comparison as they depend from superordinate choices which are out of the residents’ control.

	EF (gha/person)						
	home & energy	goods	waste	travel	food	built-up land	total
Sieben Linden	0.57	0.06	0.03	0.34	0.72	0.03	1.76
Findhorn Foundation	0.29	0.30	0.20	0.37	0.42	n/a	1.58
BedZED	0.77	0.79	n/a	0.75	1.22	n/a	3.53
Steward Community Woodland	0.24	0.64	n/a	0.30	0.66	n/a	1.84
Toarp	1.15	0.15	0.04	0.42	0.93	n/a	2.69
OUR ecovillage	0.28	n/a	0.30	0.67	1.12	0.15	2.52
Krishna Valley	0.29	n/a	n/a	0.18	0.42	n/a	0.89

Table 12: Comparison between Sieben Linden’s EF and other ecovillages’ EF

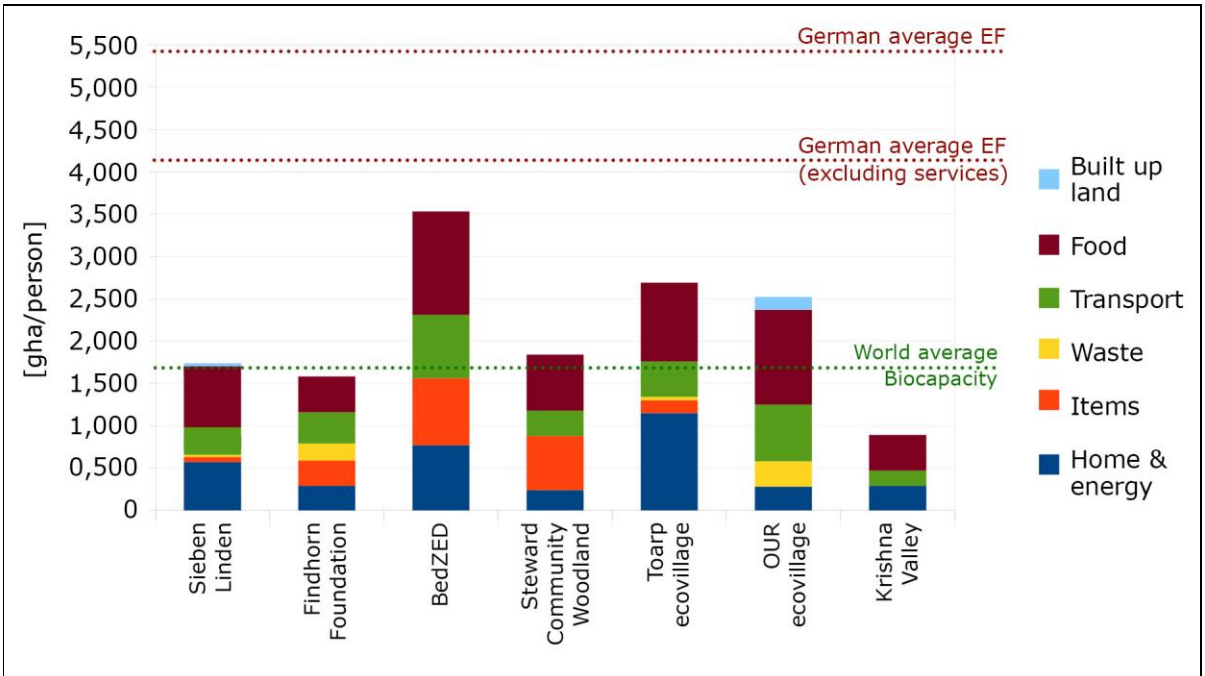


Figure 14: Comparison between Sieben Linden’s EF and other ecovillages’ EF

The EF of all cases is far below the German average. Two communities have a ‘local’ EF lower than the ‘fair share’ EF, that is to say within the world mean biocapacity – however, the addition of the EF due to public administration and other services would inevitably make them pass such threshold. Moreover, some of the ‘local’ impact categories were also not included in these studies (see Table 12); one ought to recall this to avoid unfair comparisons. For instance, values of Krishna Valley are particularly low also because they do not include several such categories. This said, in spite of covering all impact categories, Sieben Linden’s EF is lower than the average value of the six reference cases (see Table 12 and Fig. 14).

3. LCA of Sieben Linden buildings

LCA (Life Cycle Assessment) evaluates the environmental impact of a product, process, or service throughout its entire life cycle by quantifying material and energy inputs (consumption) and outputs (emissions) during the extraction of raw materials, transport, production, distribution, use and disposal.

The categories of environmental impact considered in this study are:

- Embodied Energy (EE) or Primary Energy Intensity (PEI): it represents the amount of energy needed to produce, transport to the site and dispose a product or material or to provide a service. In the case of buildings, Embodied Energy is usually measured as the amount of energy pertaining to the unit of building material, component or system. It can be expressed in mega Joules per unit of weight (MJ/kg) or volume (MJ/m^3). The EE value of a product depends not only on the production process, but also on factors such as the energy efficiency of the machinery used, the distance from the raw materials supply, the modes of transport, the sources of energy, and the local energy mix.

- Global Warming Potential (GWP): represents the amount of greenhouse gas emissions in the atmosphere related to production, transport to the site of use and disposal of a product or material or to provide a service. It is measured in $kgCO_{2eq}$, i.e. kilograms of carbon dioxide (and other polluting gases made equivalent to carbon dioxide) released to supply a unit of product, and therefore it is generally referred to as Embodied Carbon (EC).

3.1 Case studies

This section of the study deals with the analysis of two Sieben Linden buildings: Libelle and Villa Strohbunt for which sufficient data were available.

Libelle is a residential building with a surface area of 365 m^2 on two storeys, completed in 2012, designed by architect Dirk Scharmer.

The building features continuous foundations of reinforced concrete, a layer of gravel and a concrete screed. The loadbearing structure is made of wooden elements embedded in the perimeter walls, which are insulated with straw bales and plastered with lime externally and clay inside. The self-supporting internal partition walls are made of calcium silicate blocks 175 mm wide, plastered with 15 mm clay. The roof is single pitched sloping to the north; timber rafters are 6x36 cm and the space between them is infilled with straw insulation. ‘Green’ building materials were locally sourced from the market and the house was erected by professionals.

Villa Strohbunt is a two-storey, 102 m^2 building designed and self-built between 2001 and 2004 by Björn Meenen, Martin Stengel and Silke Hagmaier with the help of volunteers. It was created as a shared space but it is now used as a living space.

Its foundation of 24 granite reused plinths support the ground floor beams above grade. It has a half-timber structure (*Fachwerk*) in round logs of pine, placed inside the perimeter walls made of clay-plastered straw bales. The internal space is free from columns thanks to the use of a solid wood floor (*Dippelbaumdecke*). The partition walls are made of clay bricks, usually plastered. The timber used in the construction comes from the ecovillage's forest, hand-felled and hand-worked, and transported by horse to the building site; it was assembled using traditional tools. Motor tools were just employed to transport foundation stones, straw bales and clay. Straw was partly from the first organic harvest of Sieben Linden fields and partly purchased in the area; clay and sand were dug from the ground of Sieben Linden. Other construction products such as foundation stones, pantiles, windows and gutters have been supplied locally; some of them were salvaged from other buildings.

3.2 Boundary of study and source of data

We chose to draw as much data as possible from a single source using transparent principles and methods. Thus reference was made to the Inventory of Carbon and Energy (ICE) of the University of Bath (Hammond; Jones, 2011), which contains relevant information on data sources. The four criteria used for their selection were:

1) compliance with ISO 14040 and 14044;
2) definition of system boundaries from cradle to gate;
3) country of origin: for most of the materials it was necessary to refer to international sources but with a preference for UK sources;
4) year: the most recent ones have been preferred, in particular as regards the Embodied Carbon.

Data in the ICE do not include carbon absorbed and stored in plants (biosequestration). When a tree grows, it subtracts carbon dioxide from the atmosphere, which becomes part of its structure; this carbon remains bound in the material until it is burned or decomposes. To widen our analysis, we decided to perform calculations both including and excluding carbon stored in vegetal materials; data missing from the ICE were obtained from other sources, such as Berge (*2009).* The boundaries adopted in this study are the same of the ICE: from cradle to gate, i.e. from the extraction phase to manufacturing phase – the energy used in the construction phase and the operational phase are not accounted for. This choice is due to data availability. However the operational phase is included in § 2.

The main source of information related to Libelle was the bill of quantities, integrated by technical drawings and building photos that allowed to resolve some inconsistencies or difficulties in identifying the elements. (In practice, a complete set of new technical drawings has been created to give every building part its physical place and cross-check the quantities employed.) Items generically listed in the bill of quantities (that is, not associated with a specific product) were associated with building products available on the German market. Some building elements could not be included in the calculation – either because not shown in the bill of quantities (i.e. metal joints of the wooden structure), or because of lack of data (i.e. services). It was not possible to ascertain to which elements 17% of the total timber appearing in the bill of quantities refers to – however, such amount was included in the calculation.

Regarding Villa Strohbunt, a synthetic bill of quantities contained in a study by the Institute for Energy Technologies of TU Berlin (2006) was used.

All salvaged elements – such as foundation stones, floor tiles, wooden ties connecting the straw bales, windows, doors, finishing plaster layer, roof tiles – have not been accounted. This approach is shared by the aforementioned study, since the EE and emissions of elements ought only to be attributed to the building where they were used for the first time. Moreover, as in the case of Libelle, it was not possible to find information on the metal joints which are therefore excluded from the calculation.

3.3 PEI and GWP calculations

In order to calculate the PEI, it was necessary to associate one or more material(s) to each item listed in the bill of quantities and calculate its total weight, when not specified. Each material was then associated with the corresponding value of Embodied Energy [MJ/kg] taken from the ICE.

In the case of Villa Strohbunt, clay, as well as pine- and fir-wood were obtained from site with no machinery; timber was dried naturally. For this reason, their EE was approximated to zero. Table 13 and Figs. 15-16-17-18 show the results obtained.

material	Libelle		Villa Strohbunt	
	weight [t]	PEI [MJ]	weight [t]	PEI [MJ]
steel	1.45	30,370	-	-
titanium zinc, aluminium	1.07	141,742	-	-
polyethylene, polypropylene	0.83	69,682	-	-
epoxy resin	0.34	47,154	-	-
paint	0.82	48,624	-	-
fibreglass	0.13	3,610	-	-
glass	2.84	42,594	0.54	-
granite	-	-	17.96	-
gravel, sand	73.89	6,133	33.46	2,710
concrete, cement	88.08	67,582	0.02	84
lime	11.11	58,863	-	-
calcium silicate	97.68	116,507	-	-
ceramics	0.98	9,259	-	-
bricks	4.09	26,607	3.11	3,432
clay	37.63	18,816	11.50	-
hemp, jute, straw, wattle	15.42	6,487	8.27	1,985
cellulose, wood fibres	3.48	66,471	-	-
timber	49.24	520,998	28.22	74,504
other	1.63	18,243	0.91	-
total	390.72	1,299,742	104.00	82,715
total per m^2	1.07	3,561	1.02	811

Table 13: Libelle mass and PEI and Villa Strohbunt mass and PEI

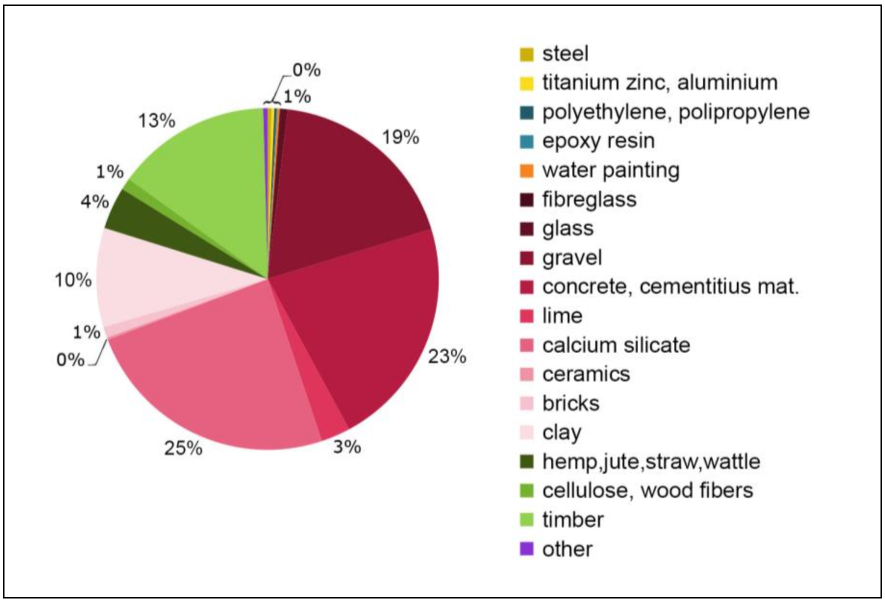


Figure 15: Libelle mass

The total weight of Libelle is 390.71 tons (i.e. 1,07 t/m^2). As 10 people live in the building, this equals 39.07 t/person.

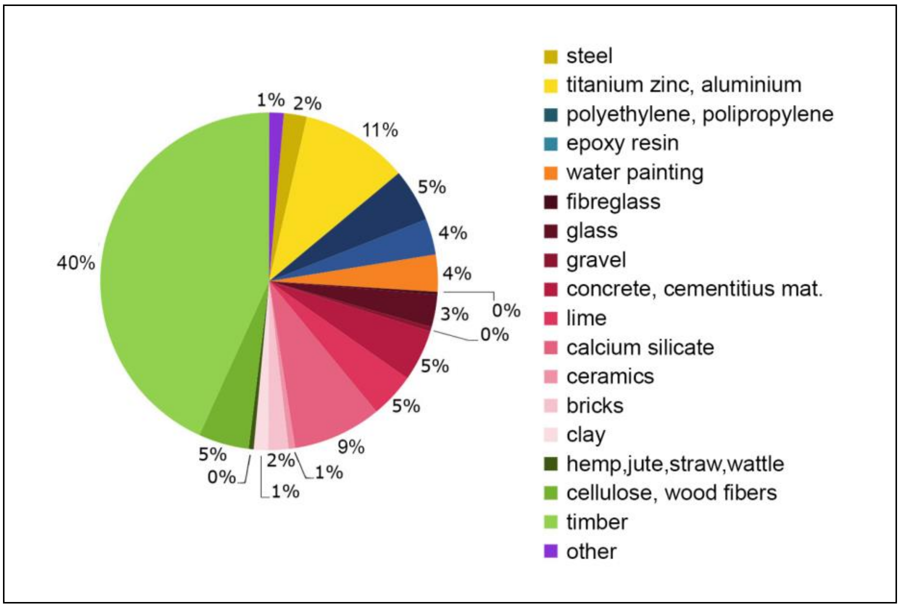


Figure 16: Libelle PEI

Global PEI for Libelle is 1,299 GJ, which translates into 3.56 GJ/m^2, and 129.97 GJ/person.

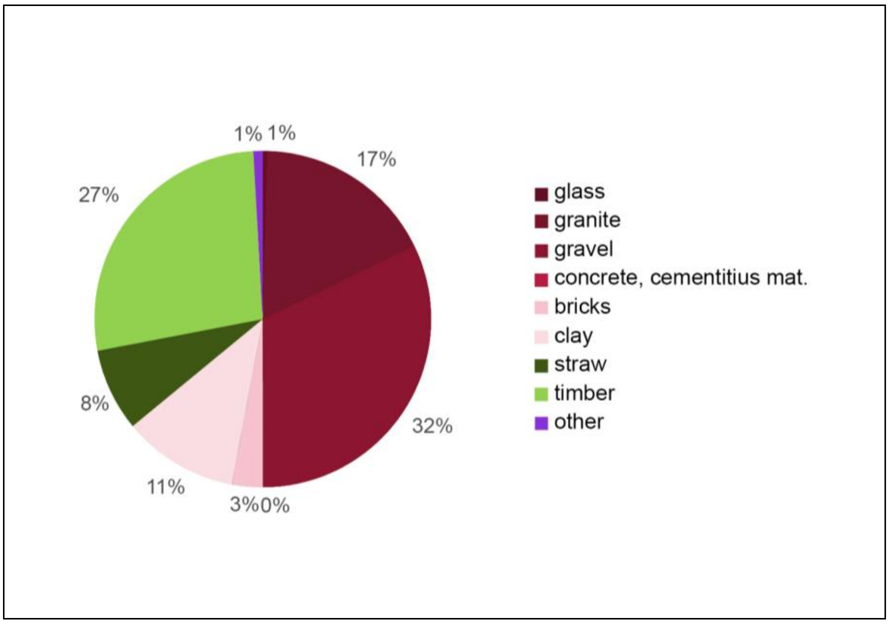


Figure 17: Villa Strohbunt mass

The global weight of Villa Strohbunt is 104 tonnes (1.04 t/m^2), but salvaged material constitutes the 23% of the building by weight, so the weight of the materials taken into account in the subsequent calculations (PEI, GWP) is 80.45 tonnes. At the present 6-person occupation, per capita weight is 17.33 t/person.

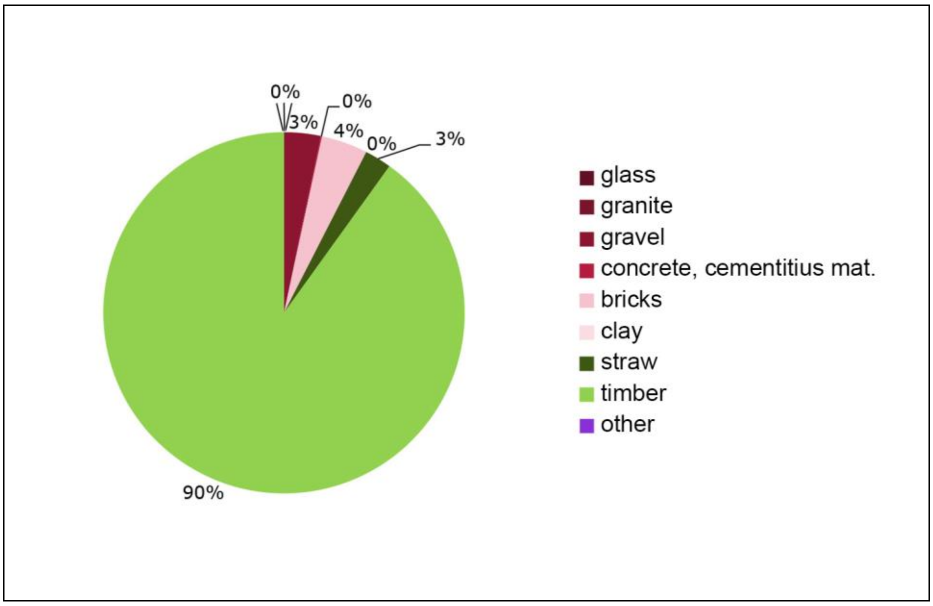


Figure 18: Villa Strohbunt PEI

Global PEI for Villa Strohbunt is 82.71 GJ, which results in 0.81 GJ/m^2, and 13.79 GJ/person.

To calculate GWP, it was decided to not use the ICE database coefficients directly – instead, values were normalized to the mix of German energy sources for the major industries, as by the

German Statistics Office.[12] Regarding conversion factors from energy to CO_{2eq} emission of fossil fuels, data from the German Federal Environment Agency (UBA) were used (Juhrich 2016:45-47). The German electricity mix was obtained from the German Statistics Office and refers to 2016 (Kono, Ostermeyer and Wallbaum 2017:3).

The results obtained are approximations: first because fossil fuels conversion factors return the $kgCO_2$ only and not total amount of GHGs; secondly because only emissions due to burning fuels were considered, not the chemical reactions that occur during the processing of certain materials (such as cement calcination).

In the case of Villa Strohbunt, its GWP was calculated for those materials hypothesized as of industrial origin. For instance, felling with an electric chainsaw and kiln-drying have been included in the calculation of the GWP of timber. Table 14 and Figs. 19-20 contain the results:

material	GWP [$kgCO_{2eq}$]	
	Libelle	Villa Strohbunt
steel	3,014.25	-
titanium zinc, aluminium	14,067.99	-
polyethylene, polypropylene	8,712.63	-
epoxy resin	5,895.79	-
paint	4,336.46	-
fibreglass	318.87	-
glass	3,762.07	-
gravel, sand	541.66	239.39
concrete, cement	5,963.64	7.39
lime	5,199.07	-
calcium silicate	10,290.40	-
ceramics	817.80	-
bricks	2,350.09	303.13
clay	1,661.90	-
hemp, jute, straw, wattle	356.10	108.96
cellulose, wood fibres	5,499.42	-
timber	29,278.35	5,608.60
other	1,666.22	-
total	103,732.71	6,267.48
total per m^2	284.20	61.45

Table 14: Libelle and Villa Strohbunt GWP

[12] https://www.destatis.de/EN/FactsFigures/EconomicSectors/Energy/Use/Tables/EconomicBranch15.html (Last accessed December 2017).

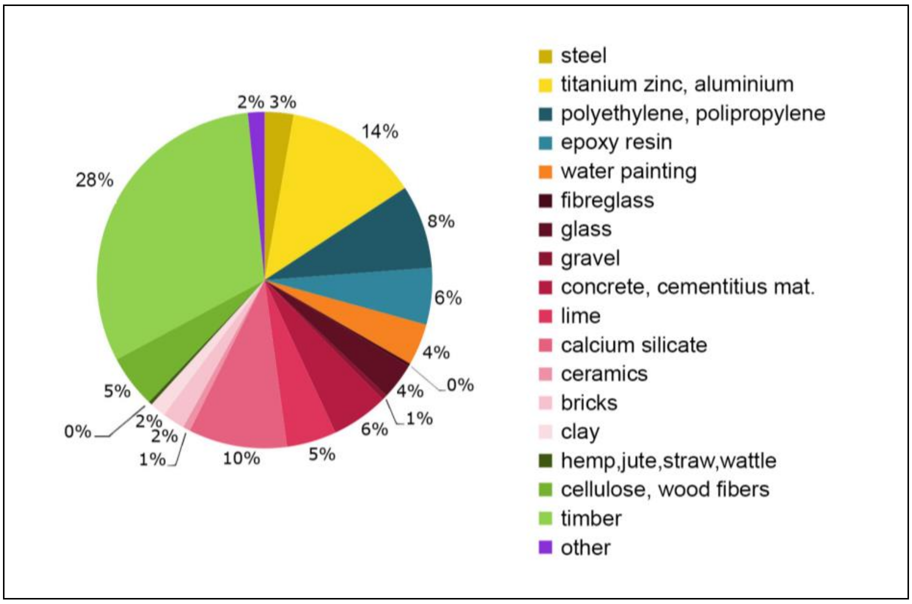


Figure 19: Libelle GWP

The total CO_{2eq} emissions of Libelle are 103.73 t (0.28 tCO_{2eq}/m^2 and 10.37 tCO_{2eq}/person).

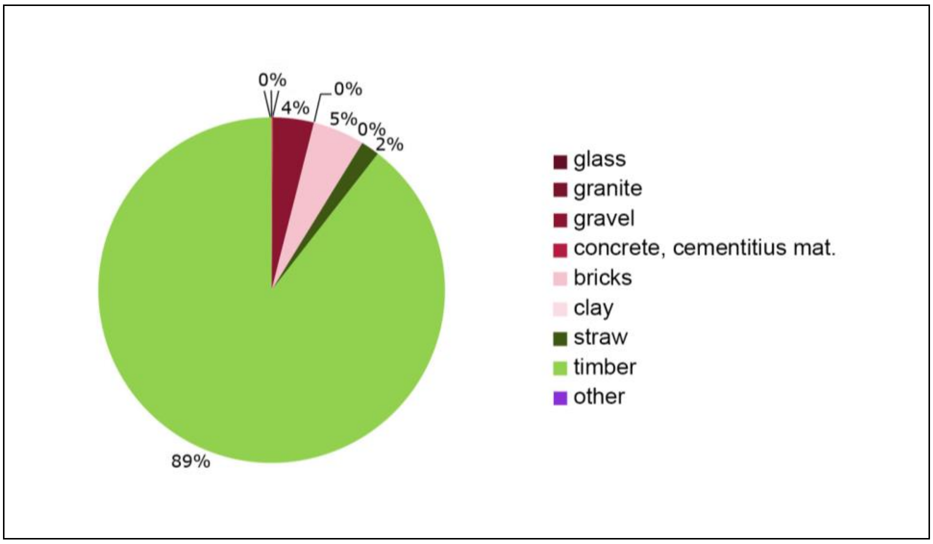


Figure 20: Villa Strohbunt GWP

The total of CO_{2eq} emissions of Villa Strohbunt are 6.27 t or 0.06 tCO_{2eq}/m^2 and 1.04 tCO_{2eq}/person.

So far, positive GWP values have been used for vegetal origin elements. If we now subtract the CO_2 sequestered by the living plants, Libelle's GWP becomes 46.21 tCO_{2eq} (i.e. 0.13 tCO_{2eq}/m^2 and 4.62 tCO_{2eq}/person) and Villa Strohbunt's -23.02 tCO_{2eq} (-0.23 tCO_{2eq}/m^2 and -3.84 tCO_{2eq}/person).

3.4 Comparisons

3.4.1 Comparison with Wegmann-Gasser house

An interesting comparison can be made with a similar building: Wegmann-Gasser house in Glarus, Switzerland, designed by Werner Schmidt with a similar technology (load-bearing straw bale construction, with timber structures for floors and roof) (Bocco Guarneri 2013): see Table 15 and Figs. 21-22-23.

	weight	PEI			GWP			GWP (negative values admitted)		
	[t]	[GJ]	[GJ/m^2]	[GJ/p]	[tCO_{2eq}]	[tCO_{2eq}/m^2]	[tCO_{2eq}/p]	[tCO_{2eq}]	[tCO_{2eq}/m^2]	[tCO_{2eq}/p]
Libelle	390.72	1299.74	3.56	129.97	103.73	0.28	10.37	46.21	0.13	4.62
Villa Strohbunt	80.45	82.72	0.81	13.79	6.27	0.06	1.04	-23.02	-0.23	-3.84
Wegmann Gasser	239.32	964.79	5.33	192.96	65.59	0.36	13.12	-27.03	-0.15	-5.41

Table 15: comparison between Libelle, Villa Strohbunt and Wegmann-Gasser house results

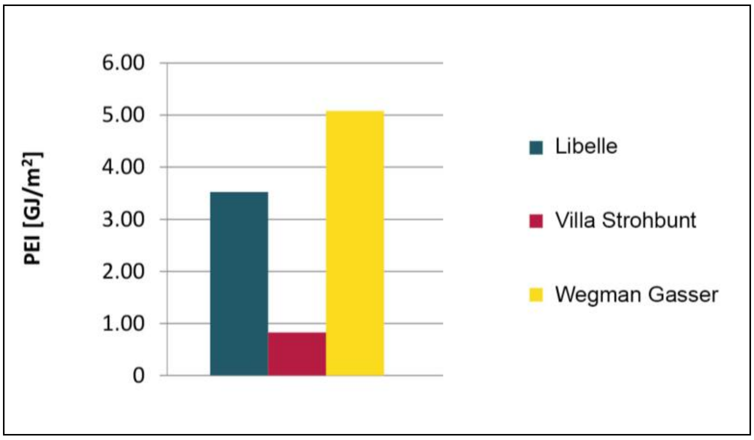


Figure 21: PEI [GJ/m2]: comparison between the three buildings

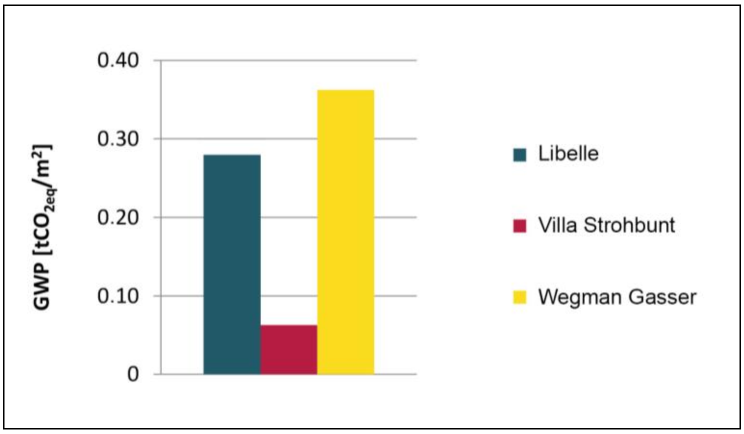


Figure 22: GWP [tCO2eq /m2]: comparison between the three buildings

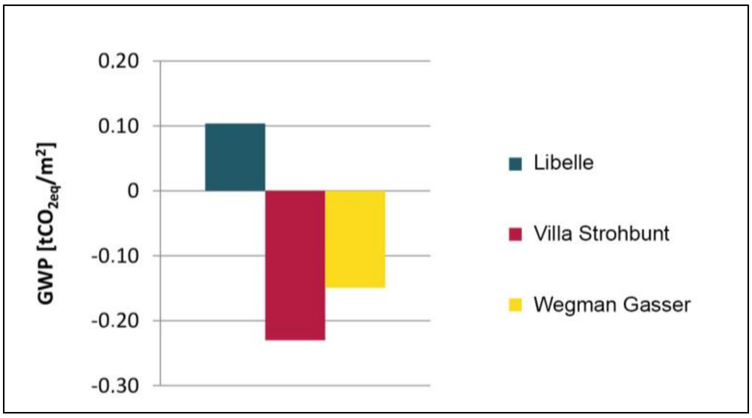


Figure 23: GWP [tCO2eq /m2] (admitting negative values): comparison between the three buildings

It is immediately apparent that Villa Strohbunt, thanks to the constructional choices (reuse of some elements and almost exclusive use of natural materials processed without the use of machinery) has the lowest values of PEI and GWP. Wegmann House has the highest values per square metre, because though the absolute amount of resources and energy is much lower (40% less in weight and 30% in PEI than Libelle), its floor surface is about 50% less than that of Libelle. However, it should be borne in mind that not all metal joints of Libelle have been computed, and this might affect the results.

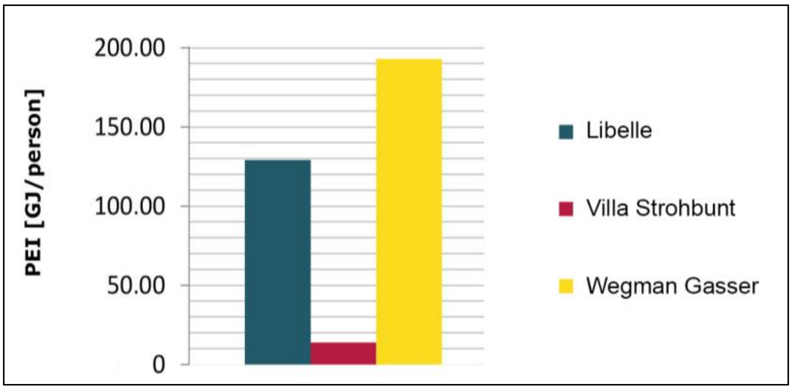


Figure 24: PEI [GJ/person]: comparison between the three buildings

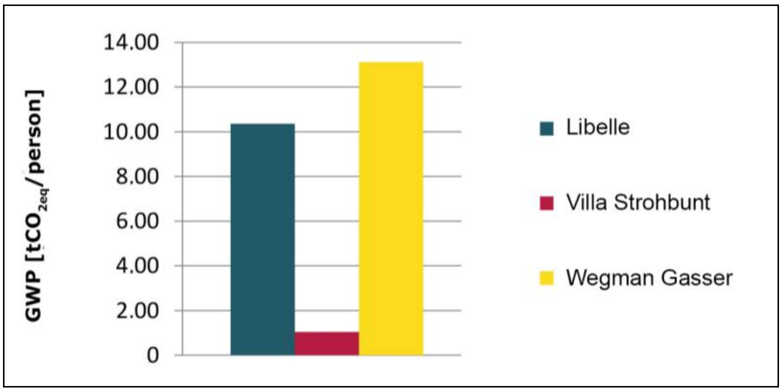


Figure 25: GWP [tCO2eq/person]: comparison between the three buildings

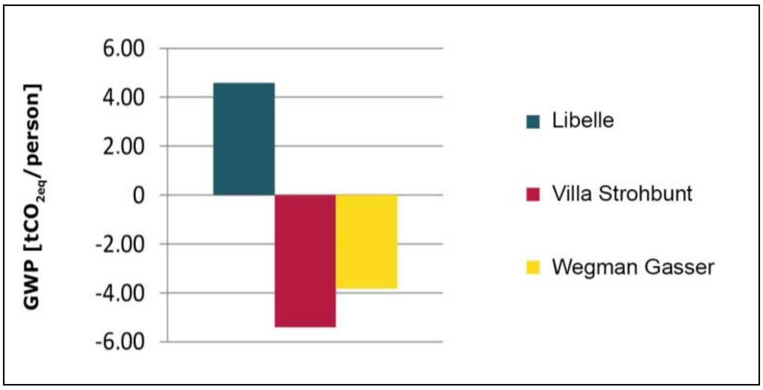


Figure 26: GWP [tCO2eq/person] (admitting negative values): comparison between the three buildings

The differences remain almost unchanged if we consider the impacts per inhabitant (Figs. 24-25-26). Villa Strohbunt remains the building with the best results.

It is interesting to note, however, that the gap between Wegmann house and Libelle values increases: the percentage of vegetal materials in the Wegmann house is about twice that of Libelle, so in the first the emissions of the other materials are compensated (and exceeded).

3.4.2 Comparison with average buildings

Another interesting comparison can be drawn between Sieben Linden buildings and average residential buildings. Unfortunately, no study has been found that provides the average environmental impact of buildings either at the national level (Germany) or at the European level. Most studies, in fact, provide collections of case studies, often selected according to different criteria. We decided to use two works as references, which allow for some extent of comparability: Dixit (2017) shows PEI values for residential buildings by continent and calculates the average value for different construction systems – timber, reinforced concrete and steel. Birgisdóttir (2016) discusses a number of case studies worldwide. As the figures in the two reference works cannot be considered representative of the European construction sector, we decided to use the mean between the highest and lowest values from both studies as a benchmark (see Table 16 and Fig. 27).

construction system	max [GJ/m^2]	min [GJ/m^2]	mean [GJ/m^2]
timber	7.70	2.30	5.00
reinforced concrete	8.75	3.20	5.98
steel			8.40

Table 16: PEI of different construction systems

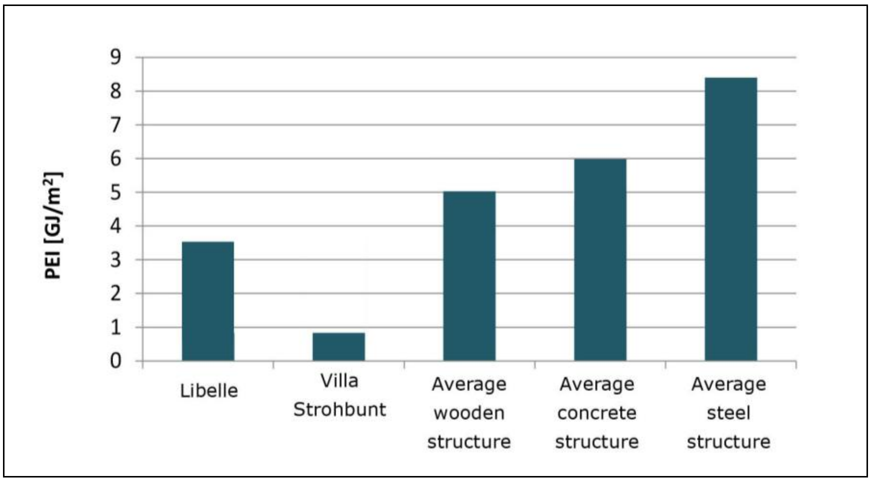


Figure 27: PEI [GJ/m^2]: comparison between Libelle, Villa Strohbunt and the mean values for the most common construction systems

Again, Villa Strohbunt has the lowest embodied energy, at 83% less than average timber structures; Libelle's PEI is 27% lower than average.

As long as emissions are concerned, it was not possible to find an average value for steel structures (see Table 17 and Fig. 28).

construction system	max [tCO_{2eq}/m^2]	min [tCO_{2eq}/m^2]	mean [tCO_{2eq}/m^2]
timber	0.45	0.09	0.27
reinforced concrete	0.65	0.15	0.40

Table 17: GWP of different construction systems

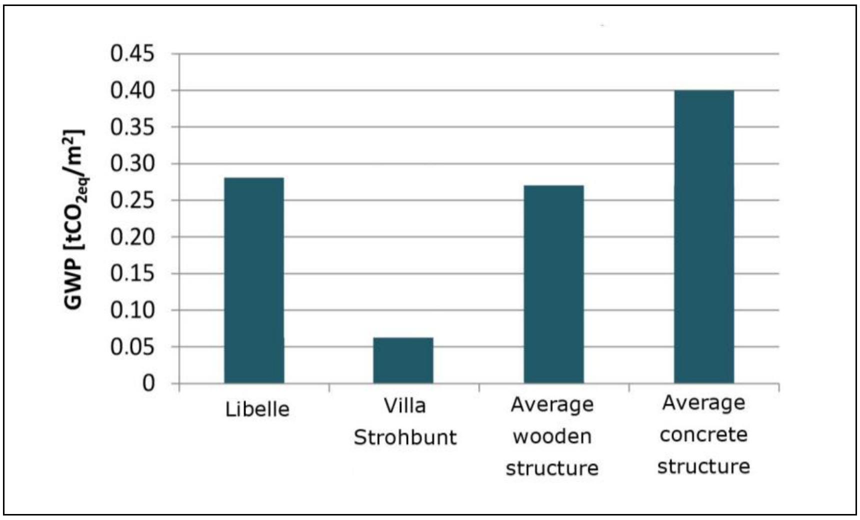


Figure 28: GWP [tCO_{2eq}/m^2]: comparison between Libelle, Villa Strohbunt and the mean values for timber and reinforced concrete buildings

Villa Strohbunt's GWP is 78% less than average timber structures; Libelle's is 3% more than average.

3.5 Discussion

The results obtained cannot be considered rigorous. This study has highlighted some limitations and problems of the methodology used.

Since there are no international standards that define this analysis uniquely, it is problematic to return a comparable result. For example, some studies take into account only the EE of construction products, others include transport operations, or only part of the energy needed to extract raw materials. This is partly due to the difficulty of sourcing data. Another critical issue is the correct estimation of input data in relation to the study boundaries. These approximations can lead to unreliable or not-comparable results. It therefore emerges that such analyses would be more valid if planned since the design phase of a building, and they were carried on during all phases of its construction. As mentioned above (§ 3.2), we had to stay within phases A1-A3 of a LCIA (from raw materials supply to building materials production) as we did not precisely know the distance travelled to the building site (A4) nor we could detailedly describe the assembly operations at the building site itself (A5). We assume they would not have altered much the picture, but obviously the more comprehensive you get, the higher the figures you obtain. On the other hand, we think that the not particularly brilliant comparison between the Libelle and the 'average timber-structure house' (§ 3.4.2) might be due to a possible expeditious and simplified calculation of the latter's EE and EC values.

However, Villa Strohbunt's values are far below both the other two case buildings and the average buildings, for all indicators. This is due to the fact that few materials, in weight and variety, have been used for its construction, most of which required simple processing without the use of machinery. Another relevant factor is the reuse of elements.

Looking at the values per square metre, it is clear than in spite of similar technology and energy performance, Libelle is more efficient (that is, is less damaging to the environment) than Wegmann house. It is also interesting to consider the values per inhabitant: the number of residents is a variable that indeed affects the results, much more so as the number of inhabitants changes (or may change) over time.

4. Ecological footprint of Sieben Linden buildings

We assess here the EF of the resources employed the same Sieben Linden buildings studied in § 3, taking into account the most significant impacts on bioproductive areas. This analysis was carried out according to the EF component method; the boundaries are from cradle to gate, as for PEI and GWP. Conversion factors (yield, eqf) are the same used in § 2.

	Libelle			Villa Strohbunt		
	gha	gha/m^2	%	gha	gha/m^2	%
energy land	26.63	0.07	23.38	1.61	0.02	4.49
forest land	87.21	0.24	76.57	34.18	0.34	95.45
built-up land	0.06	0.00	0.05	0.02	0.00	0.06
total	113.90	0.31	100.00	35.81	0.36	100.00

Table 18: Libelle and Villa Strohbunt EF

Table 18 shows that absolute EF values of Libelle are higher than those of Villa Strohbunt, which is not very telling as Libelle is a larger building. However, if we consider the unitary EF [gha/m^2], the differences between the two buildings become much smaller: in particular, Libelle's energy land is 3.5 times larger than Villa Strohbunt's, while the forest land of the latter is 1.4 times larger than Libelle's, in fact the amount of vegetal-origin building materials in Villa Strohbunt is 0.26 t/m^2 while in Libelle is 0.14 t/m^2.

Unfortunately, no other studies have been found on the EF of straw-bale buildings or ecovillage buildings for comparisons. Therefore, the Wegmann house was maintained as the benchmark, as available data allowed us to calculate its EF at 0.57 gha/m^2 (0.09 gha/m^2 energy land + 0.48 gha/m^2 forest area: see Fig. 29).

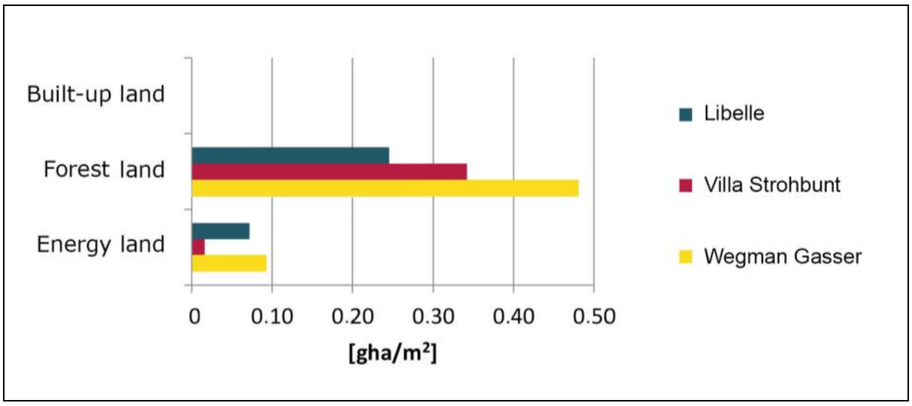


Figure 29: Comparison of Libelle, Villa Strohbunt and Wegmann Gasser EF

Wegmann house's values are the largest for each component of the EF; the total value exceeds that of Libelle by 45.6 %, and of Villa Strohbunt by 36.8 %, confirming the results of the PEI and GWP analyses. But as opposed to these, it is now Villa Strohbunt the building with the second-largest impact.

4.1 Commentary

The three components of the EF of buildings have a very different impact on the final result. The built-up land can be considered negligible, while the forest area has the highest values. This is because the buildings analysed employ large amounts of vegetal materials. Paradoxically, this variable would take lower or even zero values in buildings using other construction systems such as reinforced concrete. In fact, the EF measures the consumption of renewable resources, i.e. the land in terms of resources which the planet can regenerate. All non-renewable resources, i.e. those resources that require geological times for their reproduction, are excluded from the calculation. It is only considered the impact produced by the processing and extraction of these resources, which is expressed in CO_2 emissions and is converted into land for energy, i.e. the forest land necessary for their absorption.

This indicates that this method is inadequate to weigh non-biological components and it merely converts the PEI, attributed to them, in equivalent hectares of ‘energy land’. However, the ecological footprint method can provide a more complete result than the PEI assessment, because it does not only include the energy used in the production processes but also the consumption of materials (when of vegetal origin).

5. Comparing daily impact and construction impact

An overall assessment of the environmental impact of the ecovillage is proposed here, which takes into account both the consumption of Sieben Linden residents and the construction of buildings.

5.1 Recurring footprint and building footprint

The EF associated with the daily activities of residents has been calculated for the entire ecovillage for 2014 in § 2. It is 391.16 gha, and 3.08 gha/person (public services included). [1]

The estimate of the EF of buildings was based on the figures of Libelle, as it is satisfactorily representative of average Sieben Linden residential buildings in terms of construction techniques and surface/residents ratio (see Table 19).

	EF [gha]	unit EF [gha/m^2]
Libelle	113.90	0.31
Villa Strohbunt	35.81	0.36

Table 19: Buildings footprint

An annual construction index (1.06, based on the average amount of square metres built yearly) was then introduced to calculate the yearly average EF due to construction activities (2017-2001). The average annual EF of buildings is thus 81.19 gha and 0.64 gha/person. If we add this to [1] here above, the impact of construction accounts for 17% of the total (Fig. 30). In spite of the low impact of the ecovillage's buildings, their share is relatively high – in fact, also the EF of everyday lifestyle is low.

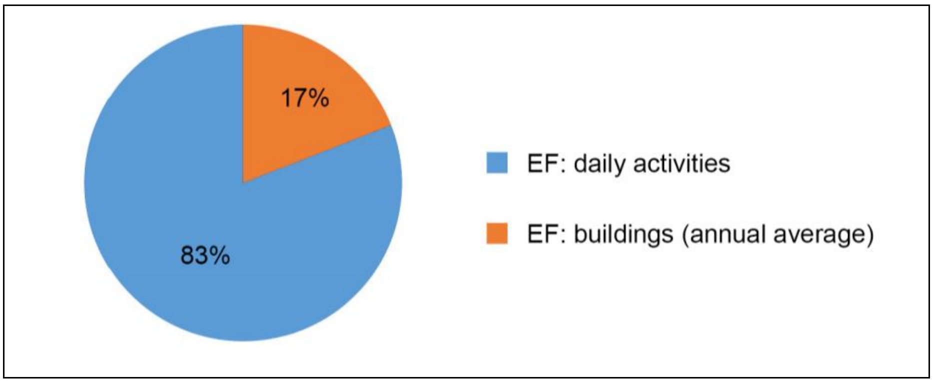


Figure 30: Comparison between daily activities footprint and buildings footprint

The EF associated with the construction of buildings is not generally considered in the calculation of the footprint of sub-national areas. This is one of the aspects that makes it difficult to compare Sieben Linden EF with national EF. In fact, the standard method for calculating the national EF considers a wide variety of impacts, including those associated with the construction of all private and public facilities. To compare the local EF with the national EF it would be necessary to align with this method, and calculate every single entry in the EF of sub-national areas assessment.

On the other hand, we can't accept the amortization of the environmental impacts of the construction activity. This would be against one of the fundamental assumptions of the EF methodology (see § 0), and anyway the actual service life of a building is unpredictable and much more dependent on social phenomena (real estate market, fashion, war...) than on technical ones; indeed, conventional service life spans (assumed as significantly smaller than 100 years) seem to promote focussing on recurrent energy performance rather than on durability and low EE.

This said, the figure 0.64 gha/person we calculated for Sieben Linden (see § 5) does not seem completely unlikely if compared with an average national value of 0.11 gha/person for residential buildings (as from EUREAPA), as Sieben Linden is growing at a much faster rate than Germany – although with low-impact materials and technologies. On the other hand both at the local level and at the national level we used the same figure as of EUREAPA for infrastructure construction (0.31 gha/person).

Table 20 and Fig. 31 show a comparison between the overall EF of the ecovillage (including individual consumption, national services, and construction) and the average German EF.

	EF [gha/person]			
	individual consumption	construction*	public services**	total
Sieben Linden (2014)	1.76	0.95	1.01	3.72
German average (2013)	n/a	n/a	n/a	5.47
German average as of 2004 (EUREAPA)	4.64	0.42	1.01	6.04

** includes residential and infrastructure construction*
*** includes public administration and leisure*

Table 20: Comparison between Sieben Linden footprint and German average footprint

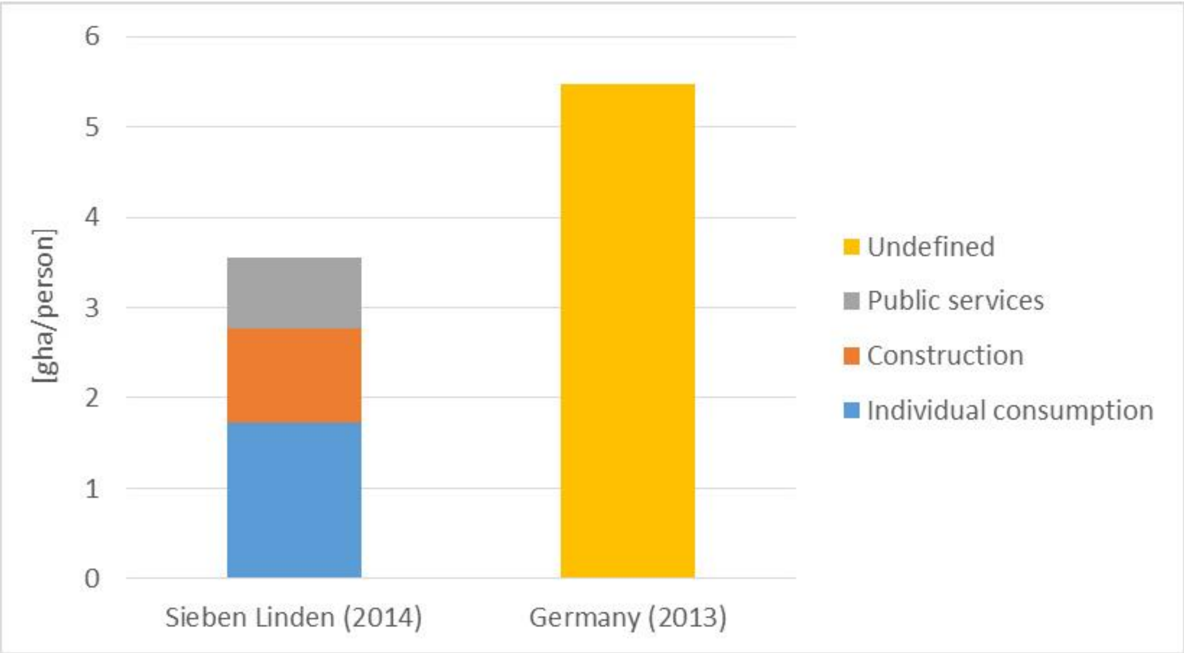


Figure 31: Comparison between Sieben Linden footprint and German average footprint

Even including the impact of construction activities, which leads to a 21% increase in value [1], the EF of Sieben Linden is 32% lower than the German national average (see Table 20 and Fig. 31).

5.2 Energy consumption and GHG emissions: operating vs. embodied impact

As meters and firewood management are centralised in the ecovillage, it was not possible to stipulate how much energy is consumed by each building. Therefore, for Villa Strohbunt the average per capita value, 16.54 GJ/person*year, was multiplied by the number of residents (this energy amount includes gas, electricity and firewood consumption). Such average value was calculated considering both residential and communal spaces as it was not possible to tell the two functions apart. However, the amount of firewood burnt in the Libelle was known (0.6 raummeter per person), so in this case an operational energy value of 9.51 GJ/person*year was obtained.

	operational energy [GJ/year]	PEI [GJ]
Libelle	95.1	1,299.7
Villa Strohbunt	99.2	82.7

Table 21: Operational energy and PEI of buildings

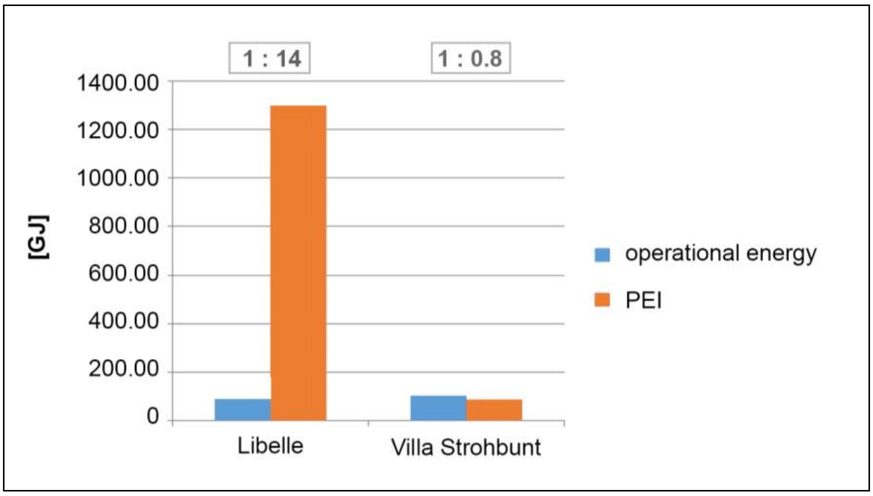


Figure 32: Comparison of operational energy and PEI of buildings

Libelle's PEI is considerably higher than operational energy: it takes almost 14 years of building use to equal it. As we have said above at § 5.1 we assume that Libelle can be acceptably considered as a proxy for the average Sieben Linden building. However, the result shown in Table 21 and Fig. 32 cannot be directly transferred to the whole ecovillage, as it should be borne in mind that many residents live in trailers rather than buildings.

In Fig. 33, we have therefore proposed a weighted version of this same analysis: The total operational energy of Sieben Linden was obtained by multiplying the figure per person by the number of people living in residential buildings; while the total PEI of Sieben Linden buildings is the sum total of a) Libelle’s unit PEI multiplied by the built-up residential area and b) Libelle’s unit PEI multiplied by the amount of communal built-up spaces weighted on the number of people living in buildings (that is, Sieben Linden population minus the people living in trailers). Refurbished buildings were assigned PEI = 0 as they are reused structures, and the impact of their upgrading has been assumed as very low.

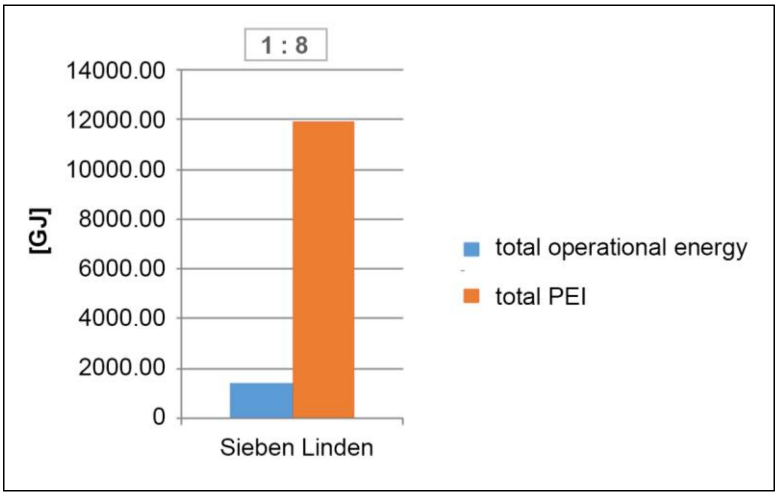


Figure 33: Comparison of total operational energy and total PEI

The estimated total PEI is now a bit more than 8 times larger than the overall operating consumption – that is, it would take more than eight years to use as much energy as in the making of the buildings. This value is lower than that obtained for Libelle (Fig. 32), as Libelle's firewood consumption is lower than Sieben Linden average.

A similar procedure was repeated for GHG emissions (see Table 22 and Fig. 34). In this case too, operational emissions values were available at the whole ecovillage level; therefore were assigned to Villa Strohbunt the average per capita value (0.29 tCO_2/person*year) multiplied by the number of residents, while for Libelle we obtained 0.17 tCO_2/person*year on the basis of the amount of firewood actually burnt.

	operational emissions [tCO_{2eq}/year]	GWP [tCO_{2eq}]
Libelle	1.74	103.73
Villa Strohbunt	1.72	6.27

Table 22: Operational emissions and GWP of buildings

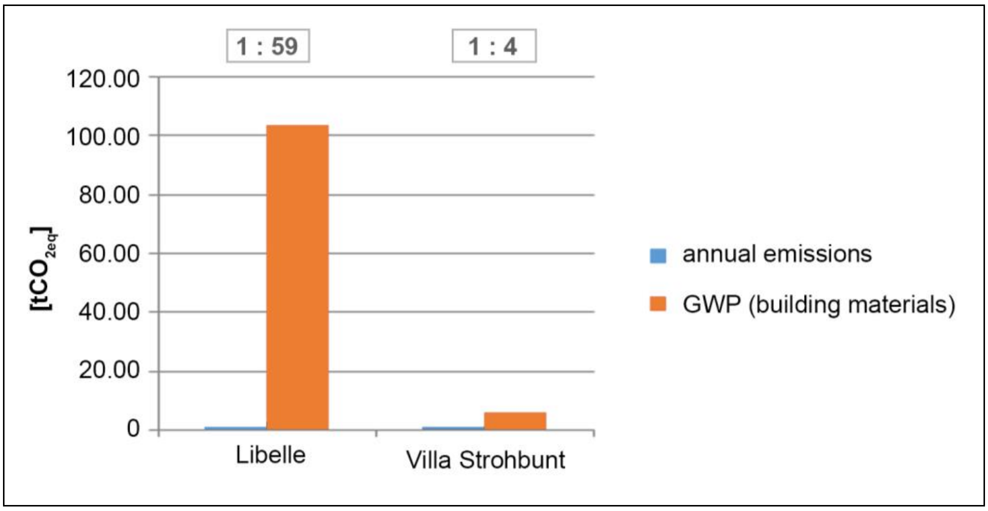


Figure 34: Comparison of operational emissions and GWP of buildings

In this case, the difference between operational and building phases is much larger. For Libelle, it takes 59 years for the two values to equalise. This depends on the energy sources used: the production of industrial building materials employed the German energy mix, while the ecovillage runs on nearly zero-emission renewable energy.

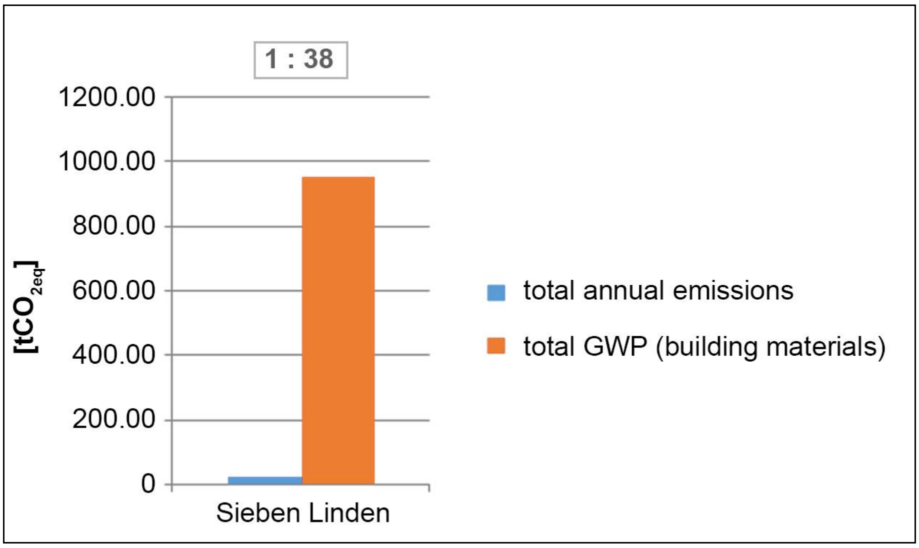


Figure 35: Comparison of total operational emissions and total GWP

Comparing the values for the whole ecovillage (Fig. 35), it would take 38 years for the GHG emitted to operate the buildings to equal the amount released when the building materials were produced. Again, this value is lower than that calculated for Libelle, because of its lower-than-average firewood consumption.

6. Final remarks and recommendations

6.1. In 2014, the territorial extension of Sieben Linden land was 82.5 ha, which corresponded to a biocapacity of 434.1 gha (3.42 gha/person). Although methodologically incorrect – as the yield factors used to calculate the EF and biocapacity are the average global one in the first case and the average national one in the second –, it might be interesting to compare this figure with Sieben Linden’s EF, which was 391.16 gha (3.08 gha/person).

6.2. A group from the University of Kassel calculated the carbon/energy footprint of Sieben Linden twelve years before us, when the residents were 52 (Dangelmeyer et al. 2004). Methodology, data retrieval and boundaries differ from our own study, making the results just partially comparable (see Table 23). However, it may be interesting to remark that in all areas there has been a reduction, the only exception is electricity (the increase is more than effaced by self-production). However, some values as of 2014 seem to be more virtuous than an average yearly value calculated on a longer time span. In particular, the average value of firewood consumption (2009-2015) has been 2.3 rm/p*y; this value obviously fluctuates depending on the mean temperature of each winter. During the very last winter, though, a decrease in temperature was not coupled to an increase of firewood consumption – it is too early to draw conclusions, but this might be the effect of the ever-increasing ratio of superinsulated buildings to trailers (see also the results shown in § 5.2).

	electricity [kWh/p*a]		firewood [rm/p*a]	propane gas [kg/p*a]	water [l/p*a]	food [kg/p*a]	travel [km/p*a]
2002	317.0		2.5	20.6	83.6	720	12,944
2014	148.5*	442.1**	1.5	18.1	61.8	690	11,417
difference (2014-2002) %	-53.2	+39.5	-40.0	-12.1	-26.1	-4.2	-11.8

* excluding consumption covered by self-production from PV panels
** total electricity consumption

Table 23: Comparison of consumption by category, 2014-2002

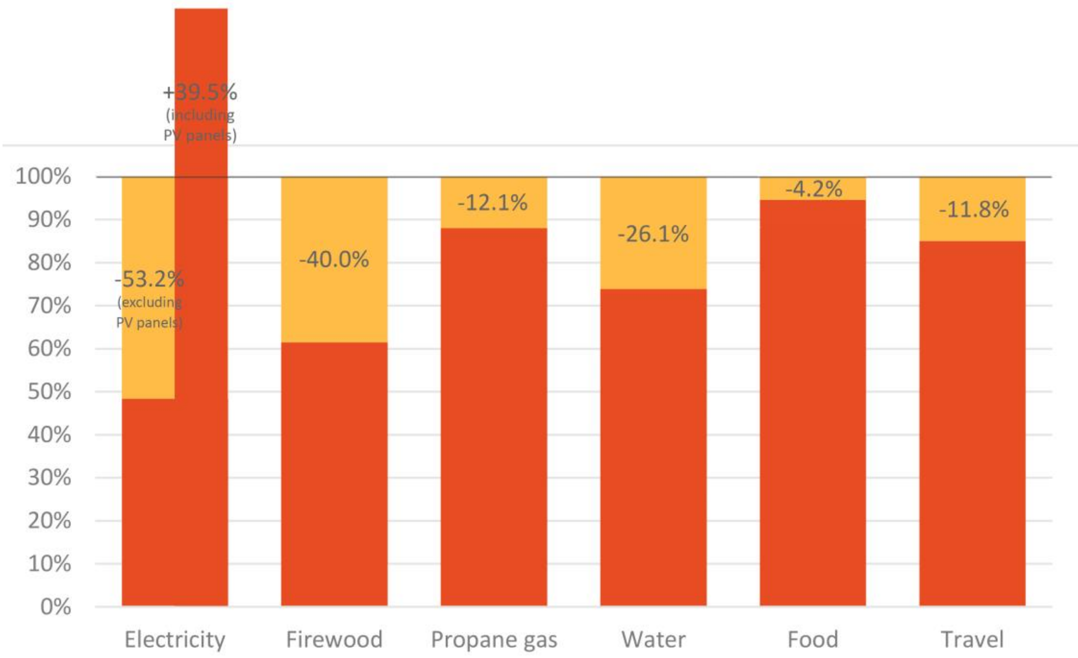


Figure 36: Comparison of consumption by category, 2014-2002

6.3. Self-sufficiency is 67.1% of electricity (PV panels); 100% of firewood (as of 2014; the self-production actually covers 65~100% of overall consumption according to year); 0% of gas; 61.3% of water (the connection to public aqueduct was recently imposed by bylaw); 29.2% of food. Self-sufficiency is not an absolute goal in terms of sustainability, and transportation does not affect much the EF in these categories. However, there seems to be scope for an increase, for instance installing a wind generator.

6.4. The actual 'public services' EF of Sieben Linden residents must be lower than the per capita share flatly applied in this calculation. In spite of this, we believe that no differentiation between citizens of a certain country should be made in this respect as it would be socially unfair, and anyhow extremely difficult to calculate. However, it should be remarked that in some areas Sieben Linden as a community – or its individual residents in their everyday lifestyle – are less dependent from public services than the average German citizen. For instance, we are referring here to infrastructure such as faeces treatment plants or kindergartens, which the community does not need as they provide such services by themselves.

6.5. Some further EF might be hidden in some cases. For instance, the remarkable (and growing) amount of time spent by Sieben Linden residents on the Internet does not only imply a local energy consumption, but also an extra remote consumption where the servers are located. Another example might be the growing tendency to buy goods from the web: it is doubtful whether the delivery of such goods has the same impact on the environment as shopping the traditional way.

6.6. Sieben Linden may be indicated as a living laboratory where a special lifestyle is experimented, which allows (among other things) to recover some of the attitudes that went lost in the modern world, particularly in terms of sharing, community, self-help, but also in terms of dependence from local environmental resources, sobriety, and reusing practices. Nevertheless there are areas where opposite trends are manifesting, such as the possession of personal electronics, which we recommend to keep under careful consideration. We suggest therefore to establish a very basic 'observatory' of environmental indicators (such as the data collected to carry this study on), one of which should be the substitution/new acquisition rate for goods, machinery and cars. More generally, we propose that such permanent observatory be equipped with a calculation tool where data analysed in this study may be yearly inputted to obtain a simplified Sieben Linden EF assessment in the future.

6.7. Generally speaking, recommendations regarding possible policies to be adopted in order to decrease Sieben Linden's EF are hard to formulate as they may depend from the environmental metrics adopted: a carbon-only or carbon-plus-energy analysis would indicate different weaknesses and strengths than an EF assessment. First of all, we would like to remark that in spite of the conspicuous share of the EF due to burning firewood, this should not disquiet as this is obtained sustainably, in the strict sense of the word (see § 2.3.1); paradoxically, if all the houses in Sieben Linden ran on nuclear energy rather than firewood, there would be an instant 15% drop in the total EF, but this would be no much good for the planet. (Environmental impact assessment methodologies based on carbon often make the impact of burning firewood = 0). This said, there are areas that might be addressed by impact reduction efforts. Travel patterns might be collectively discussed to find further economies in distances run yearly, and to optimise the private cars' occupancy. (193,949 km of car travel are shared in a year – that is, 36% of the global distance run by car. The mean car occupancy rate is 2.27 persons). Obviously a remarkable reduction of travel EF would be achieved if DB restarted operating the local railway, presently substituted by a bus service.

6.8. In Sieben Linden, there is no scope for giving priority to retrofitting buildings as very few constructions pre-dated the settlement of the community. (Of course, it remains a patent contradiction to establish a low-environmental-impact village by building a new settlement, if compared to refurbishing an existing one: but it is almost impossible to acquire a whole abandoned village where to start such an experiment, which stays valuable *per se*). However, it remains questionable whether living in trailers is as viable an option as in buildings: on the one hand, improving the thermal resistance of a trailers would entail much lower EE and EC than building a new house; on the other, no reliable information is today available as regards the trailers' firewood consumption (per square metre and per inhabitant), so to compare it with the houses. It is therefore recommended to monitor firewood consumption for single buildings and trailers (not in bulk as current practice) so to help understanding in detail which are the real consumption patterns. Moreover, it might be relevant – scientifically but also practically – to detailedly measure material and energy flows on a building site on a daily basis, in order to portray a whole and reliable picture of EE and EC associated to new construction (and therefore cover phases A4 and A5 of LCIA, see § 3.5). Another possible research might be dedicated to the detailed investigation of trailers' impacts – both in the construction and in the operation phases. Such research is furthermore relevant as today not only second-hand caravans are in use in Sieben Linden, but also new ones built in the ecovillage itself. In this field then, there is scope for an ecological impact comparison between upgrading and new construction.

6.9. For all the commendable and successful concern Sieben Linden community may have in front of limiting their EF, this research shows that it would be almost impossible to stay within the 'fair share' unless there is a drastic reduction of the EF associated to public services, government, etc.: that is, spheres which lay outside of the control of an individual or a group of citizens. It is therefore at the political level that a more courageous step towards sustainability should be taken.

6.10. Future work could, on one side, progress in merging EF and LCA methodologies in order to achieve an absolute sustainability assessment based on a bottom-up approach (that is, on the component method); and, on the other side, cover areas we did not yet investigate, which are related to a broadly-understood concept of sustainability, albeit not strictly connected to EF assessment – such as the measurement of biodiversity, and the description of the level of integration of Sieben Linden with the local society and economy.

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APPENDIXES

APPENDIX 1 – EF and BC calculation

The National Footprint Account (Lin et al. 2016) shows all steps of a national Ecological Footprint and Biocapacity calculation, from raw data to aggregate Footprint and Biocapacity values. Figure below shows an overview of components and calculations in the National Footprint Accounts.

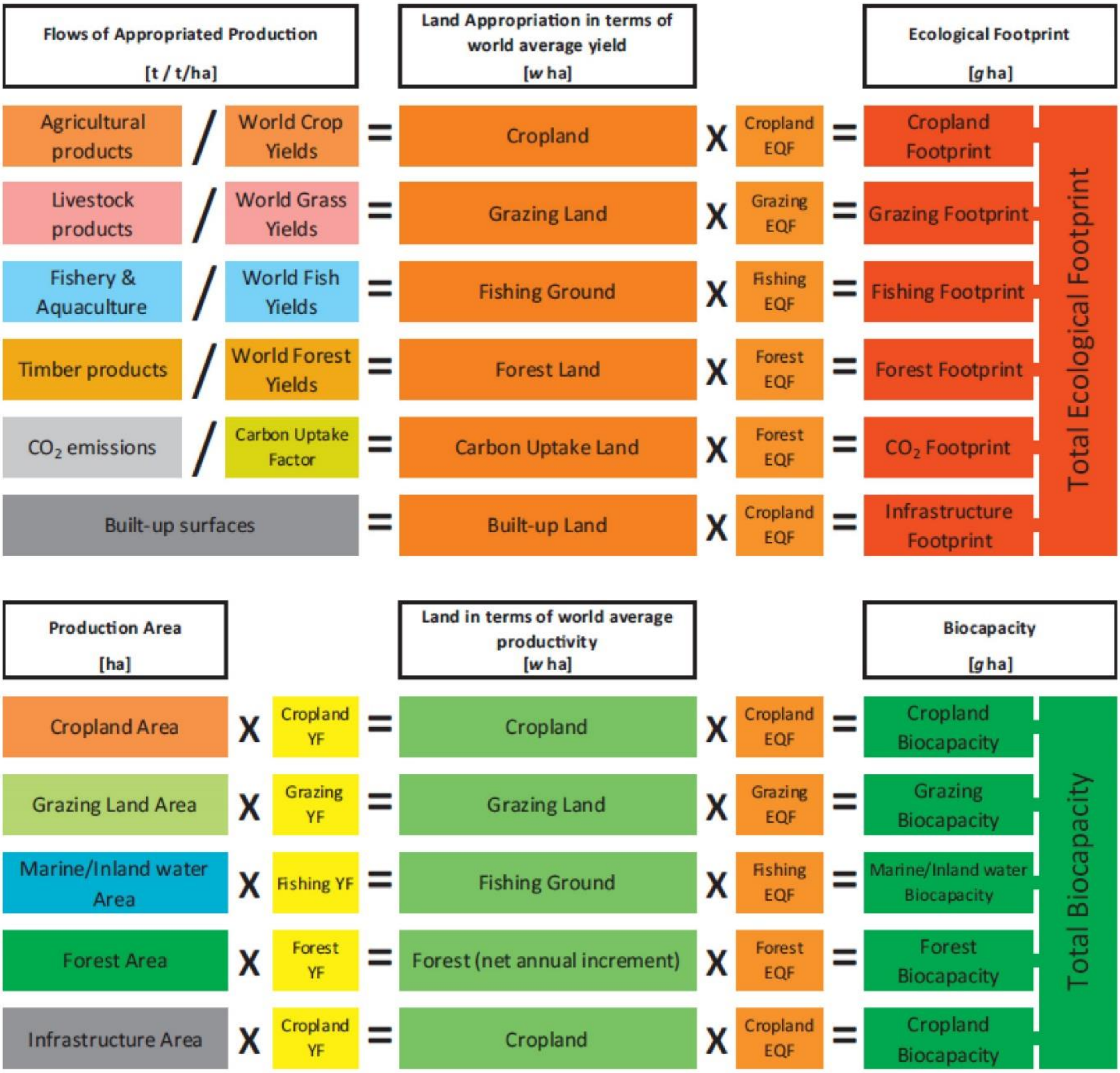

Figure 37: The framework of the National Footprint Accounts.

The basic Ecological Footprint formula is:

$$\mathrm{EF}_P = \sum_i \frac{P_i}{Y_{N,i}} \cdot \mathrm{YF}_{N,i} \cdot \mathrm{EQF}_i = \sum_i \frac{P_i}{Y_{W,i}} \cdot \mathrm{EQF}_i$$

where:

- EF_P = Ecological Footprint associated with product or waste [gha];
- P_i = amount of product extracted or waste generated, [t*yr^{-1}];
- $Y_{N,i}$ = annual national (or local) average yield for the production of product *i* or waste absorption [t*ha^{-1}*yr^{-1}];
- $YF_{N,i}$ = nation-specific yield factor for the production of product *i*. National yield factors are evaluated annually as the ratio between the yield for the production of each product *i*, in the considered nation, and the yield for the production of that same product in the world as a whole. The world yield factor is by definition equal to 1 [wha*ha^{-1}]. World average hectares are areas of a specific land type with world average productivity for that land type (e.g. one hectare of forest land with the ecological production of the average global forest hectare). World average hectares enable to visualize the physical extent of a given product if the product were produced from land (or water) having the world average productivity;
- EQF = equivalence factor for given land use type. These are multipliers which adjust different land and sea types according to their relative bioproductivity [gha*wha^{-1}];
- $Y_{W,i}$ = world average yield for the production of product *i* or waste absorption [t*wha^{-1}*yr^{-1}];

The basic Biocapacity formula is:

$$\mathrm{BC} = \sum_i A_{N,i} \cdot \mathrm{YF}_{N,i} \cdot \mathrm{EQF}_i$$

where:

- BC = Biocapacity [gha];
- $A_{N,i}$ = the estimated bioproductive area [in hectares] available for the production of product *i* at the national level;
- $YF_{N,i}$ = nation-specific yield factor for the production of product *i* [wha*ha^{-1}];
- EQF = equivalence factor for given land use type [gha*wha^{-1}].

APPENDIX 2 – Carbon Footprint of Sieben Linden

The term carbon footprint (CF) has gained increasing popularity in recent years and is now widely used in scientific literature. However, a large range of definitions of CF exist. In general, distinctions in the literature are primarily focused on two key issues: units of measurement (CO_2 or a range of GHGs, expressed in CO_{2eq}) and boundaries of the study (only direct, or both direct and indirect emissions). The definition that we considered as the most consistent with the approach of this study is that provided by the Carbon Trust: [13]

"A Carbon Footprint measures the total greenhouse gas emissions caused directly and indirectly by a person, organisation, event or product. A carbon footprint is measured in tonnes of carbon dioxide equivalent (tCO_{2eq})".[14]

The boundaries and the functional units of this CF analysis are the same as those in the EF analysis (see § 2.1). Since CF is included in the calculation of the EF,[15] data collection and revision were the same of the EF analysis (see § 2.2). However, the CF definition provided by the GFN (on which the EF analysis was based) takes a slightly different approach from the usually accepted definition of CF. In fact, it only includes CO_2 emissions derived from the combustion of fossil fuels, while emissions from firewood burning are not accounted for. In the present CF analysis all emissions, derived from both fossil and biotic sources combustion, are included.

In both EF and CF calculations data were expressed in CO_2 or in CO_{2eq} depending on the available data – in most cases, CO_{2eq}. We assume this choice is acceptable since CO_2 is by far the largest component of emissions produced by industrial processes.

The total CF for Sieben Linden is 6,392.35 $kgCO_{2eq}$/person; for the whole ecovillage it is 811,828.45 $kgCO_{2eq}$. Table 24 and fig. 38 below show a breakdown of the categories.

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[13] The Carbon Trust is an independent, expert partner of leading organisations around the world, helping them contribute to and benefit from a more sustainable future through carbon reduction, resource efficiency strategies and commercialising low carbon technologies.

https://www.carbontrust.com/about-us/ (Last accessed January 2018).

[14] https://www.carbontrust.com/media/44869/j7912_ctv043_carbon_footprinting_aw_interactive.pdf (Last accessed January 2018).

[15] In Ecological Footprint accountancy, the emissions of CO_2 are converted into biologically productive areas necessary for absorbing it (energy land). This Carbon Footprint is added to the Ecological Footprint because it is a competing use of bioproductive space, as increasing CO_2 concentrations in the atmosphere are considered to build ecological debt up.

https://www.footprintnetwork.org/resources/glossary/ (Last accessed January 2018).

components		CF [$kgCO_{2eq}$/person]	CF [%]
energy	electricity	0.00	0.00
	firewood	192.64	3.01
	solar panels	24.13	0.38
	propane gas	66.58	1.04
goods	items	94.06	1.47
waste	waste	102.46	1.60
travel	travel	1,233.89	19.30
food	food	728.59	11.40
other	services	3,950.00	61.79
total		6,392.35	100.00

Table 24: overall Carbon Footprint

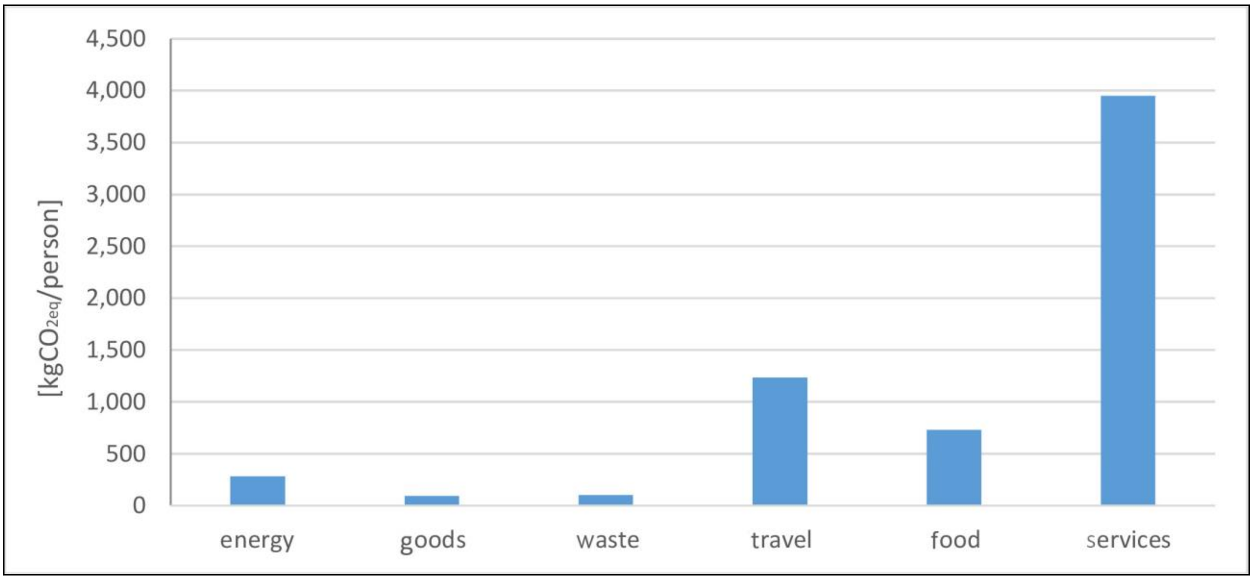

Figure 38: overall Carbon Footprint

The CF is dominated by the impact of services, which represent the 62% of total footprint. This part is ascribed to Sieben Linden residents as German citizens and cannot be directly influenced by their lifestyle choices.

Excluding the services footprint, the residents' footprint is 2,442.35 $kgCO_{2eq}$/person. The greatest contributor to the locally-controlled share of the footprint is travel (50%), mainly due to the use of cars (which represent 61% of it). Food footprint is 30%, mostly due to production and packaging (transportation is just 5%). Energy footprint is less than 12%, mainly derived from firewood combustion. Waste and goods do not affect much the overall footprint, as their sum represents about 8% of the locally-controlled share of CF.

Comparison: Sieben Linden vs. German average

Table 25 and figs. 39-40 below show the CF of Sieben Linden residents compared to that of average German citizens. Data on German CF (as of 2014) are available through DESTATIS.[16] These data have been subdivided according to EUREAPA category shares in 2004,[17] as DESTATIS data are arranged according to categories that are spurious with those adopted in the present study.

category	Germany (2014)		Sieben Linden (2014)		ratio
	CF [$kgCO_{2eq}$/person]	CF [%]	CF [$kgCO_{2eq}$/person]	CF [%]	(Sieben Linden / Germany * 100)
energy	2,533.34	19.25	283.35	4.43	11.18
goods and waste	1,989.89	15.12	196.52	3.07	9.88
travel	2,374.49	18.04	1,233.89	19.30	51.96
food	1,998.25	15.18	728.59	11.40	36.46
services	3,950.00	30.01	3,950.00	61.79	100.00
other services*	314.05	2.38	-	-	-
total	13,160.00	100.00	6,392.35	100.00	48.57

** include communication, leisure, tourist facilities, etc.*

Table 25: comparison between Sieben Linden and German average carbon footprints

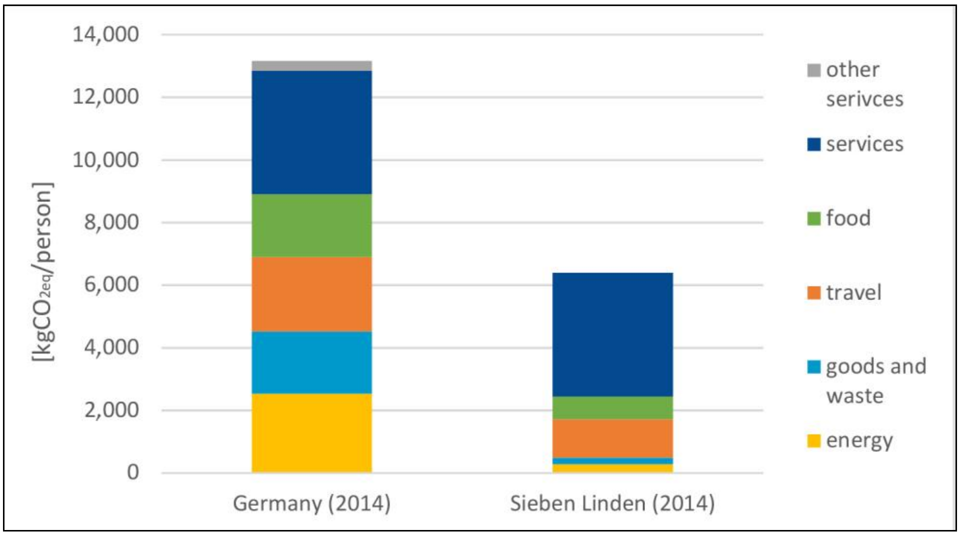

Figure 39: comparison between Sieben Linden and German average carbon footprints

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[16] https://www.destatis.de/EN/FactsFigures/NationalEconomyEnvironment/Environment/EnvironmentalEconomicAccounting/MaterialEnergyFlows/Tables/ProductionFactorsPollutants.html (Last accessed January 2018).

[17] https://www.eureapa.net/explore/?consumer_id=2&impactgroup_id=1&region_id=9 (Last accessed January 2018).

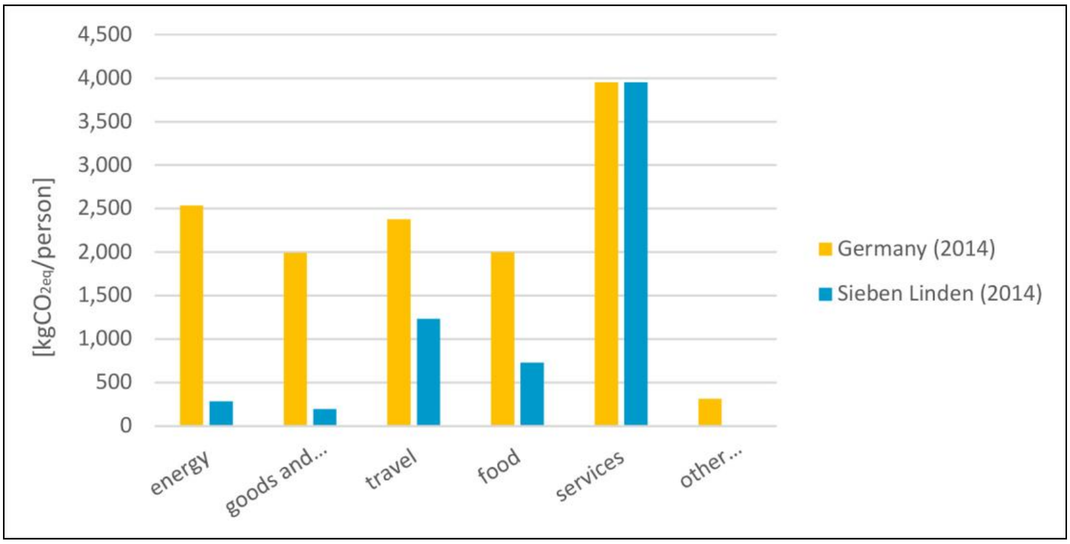


Figure 40: Breakdown of Sieben Linden and German average carbon footprints

As the national average data do not include a heading for waste – possibly because associated with the category of products that generate it – the impact of waste produced by ecovillage residents has been added to that of goods. Values for services are by definition the same, as we employed the national average for Sieben Linden as well; whereas we were not able to assess the impact of 'other services' (which include communication, leisure, tourist facilities, etc.) for Sieben Linden.

In all categories (services excluded), Sieben Linden fares significantly better than average. Energy and goods are almost 90% lower, while food is 36%. Travel is approximately one half of the national mean. In sum, the overall EF of Sieben Linden is 49% of the German average.

Comparison: Sieben Linden 2014–2002

A group from the University of Kassel calculated the CF of Sieben Linden in 2002, when the residents were 52 (Dangelmeyer et al. 2004). Methodology, data retrieval and boundaries differ from our own study, making the results only partially comparable. However, it may be interesting to make this comparison, pointing out two aspects:

- data concerning 2002 only account for residents' impact within the ecovillage; on the other hand, data from 2014 were normalized to represent the whole year impact (see § 2.2). Therefore, in this comparison non-normalized data were used.
- because of the lack of data in 2002, some categories (solar panels, goods, waste, and services) have been excluded from the comparison.

	2002		2014		ratio (2014 / 2002 * 100)
	[$kgCO_{2eq}$/person]	[%]	[$kgCO_{2eq}$/person]	[%]	
energy	238.04	9.06	193.93	9.82	81.48
travel	1,530.00	58.22	1,234.00	62.51	80.65
food	860.00	32.72	546.19	27.67	63.51
total	2,628.00	100.00	1,974.12	100.00	75.12

Table 26: comparison between Sieben Linden CF in 2002 and 2014

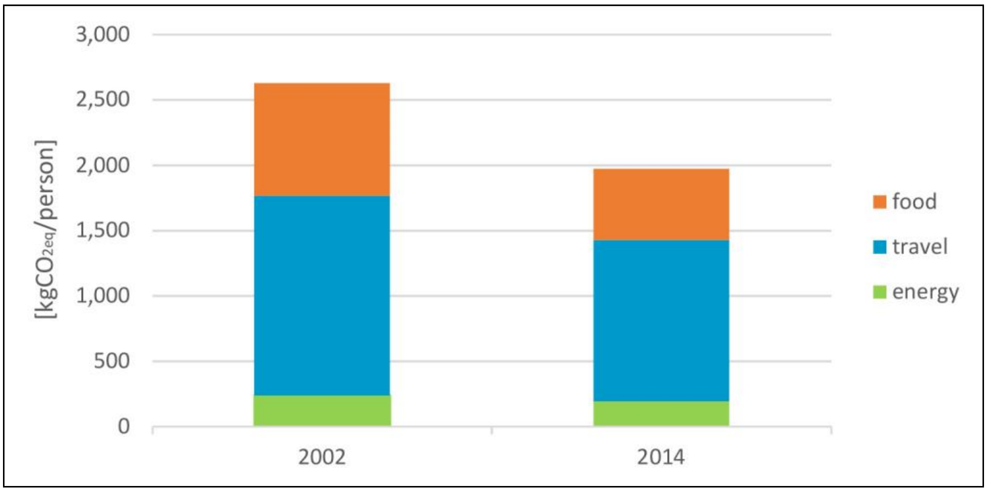


Figure 41: comparison between Sieben Linden CF in 2002 and 2014

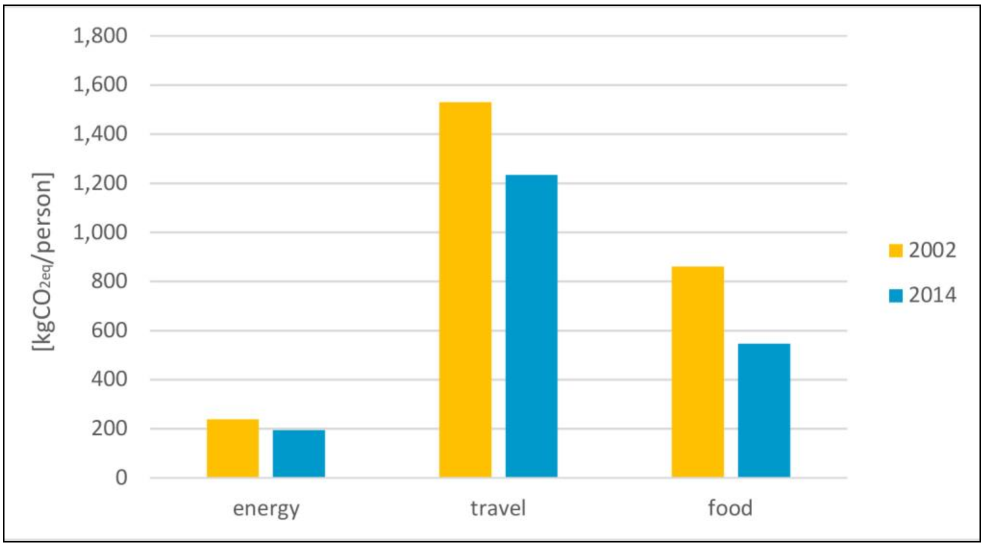
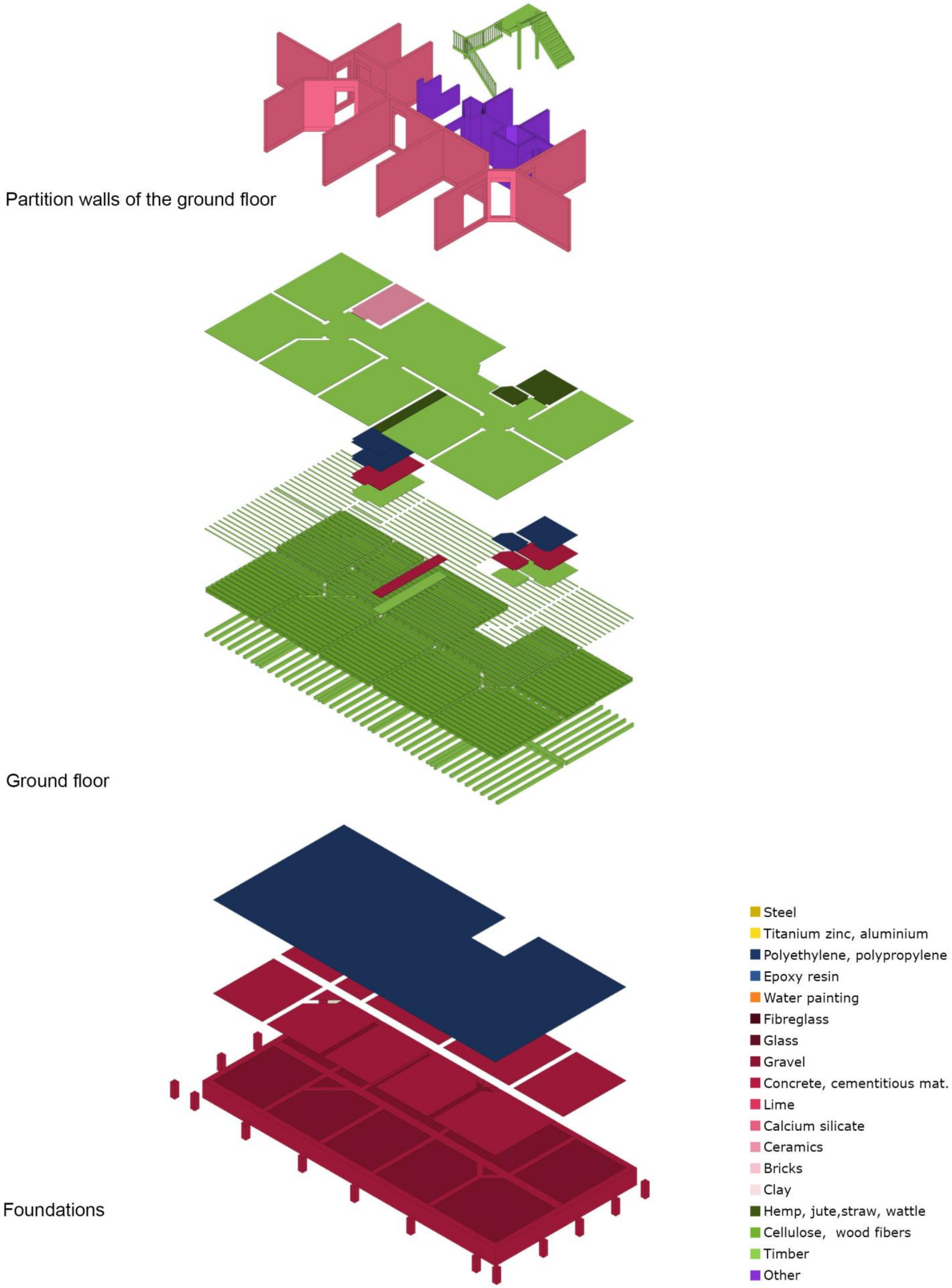


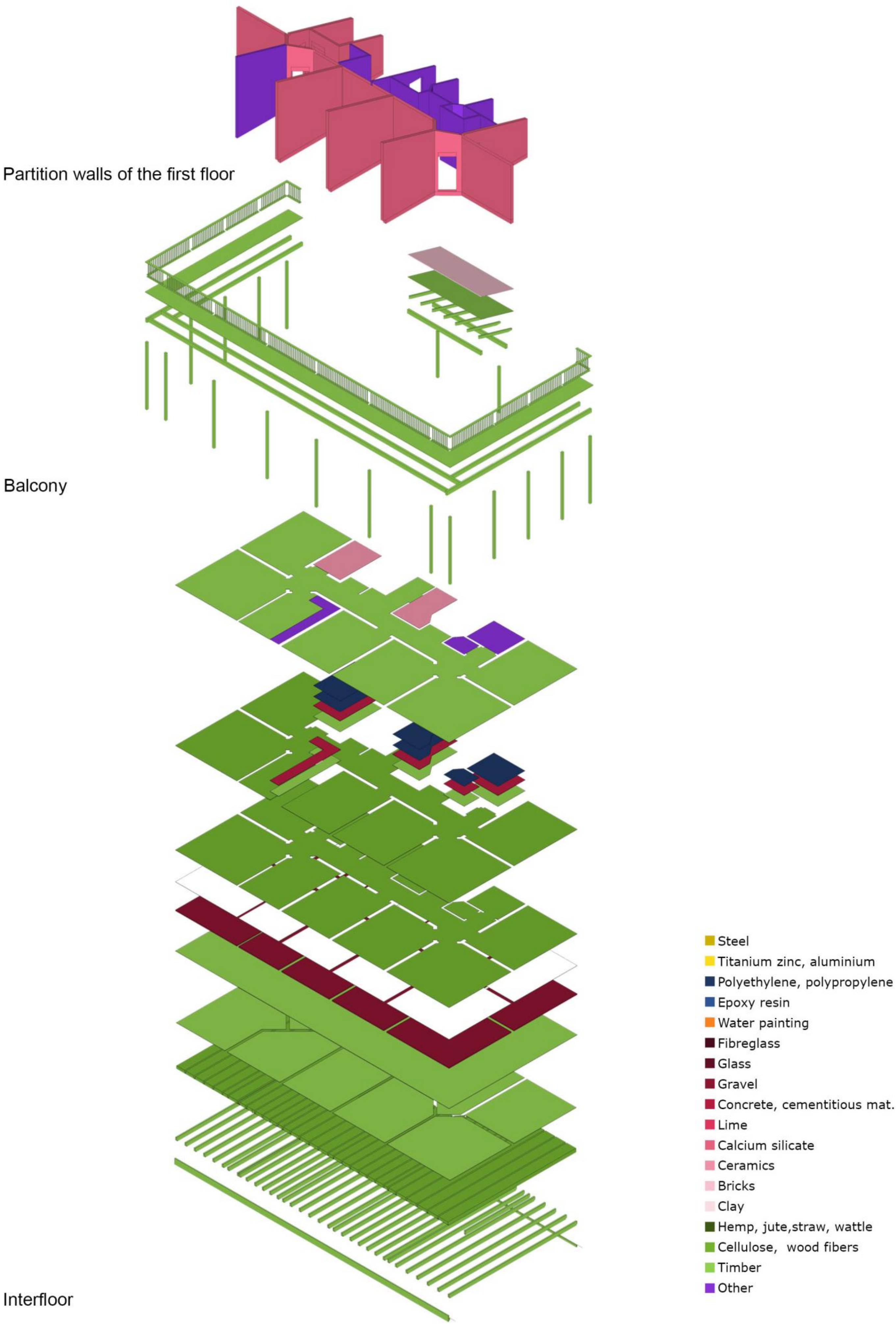
Figure 42: Breakdown of Sieben Linden CF in 2002 and 2014

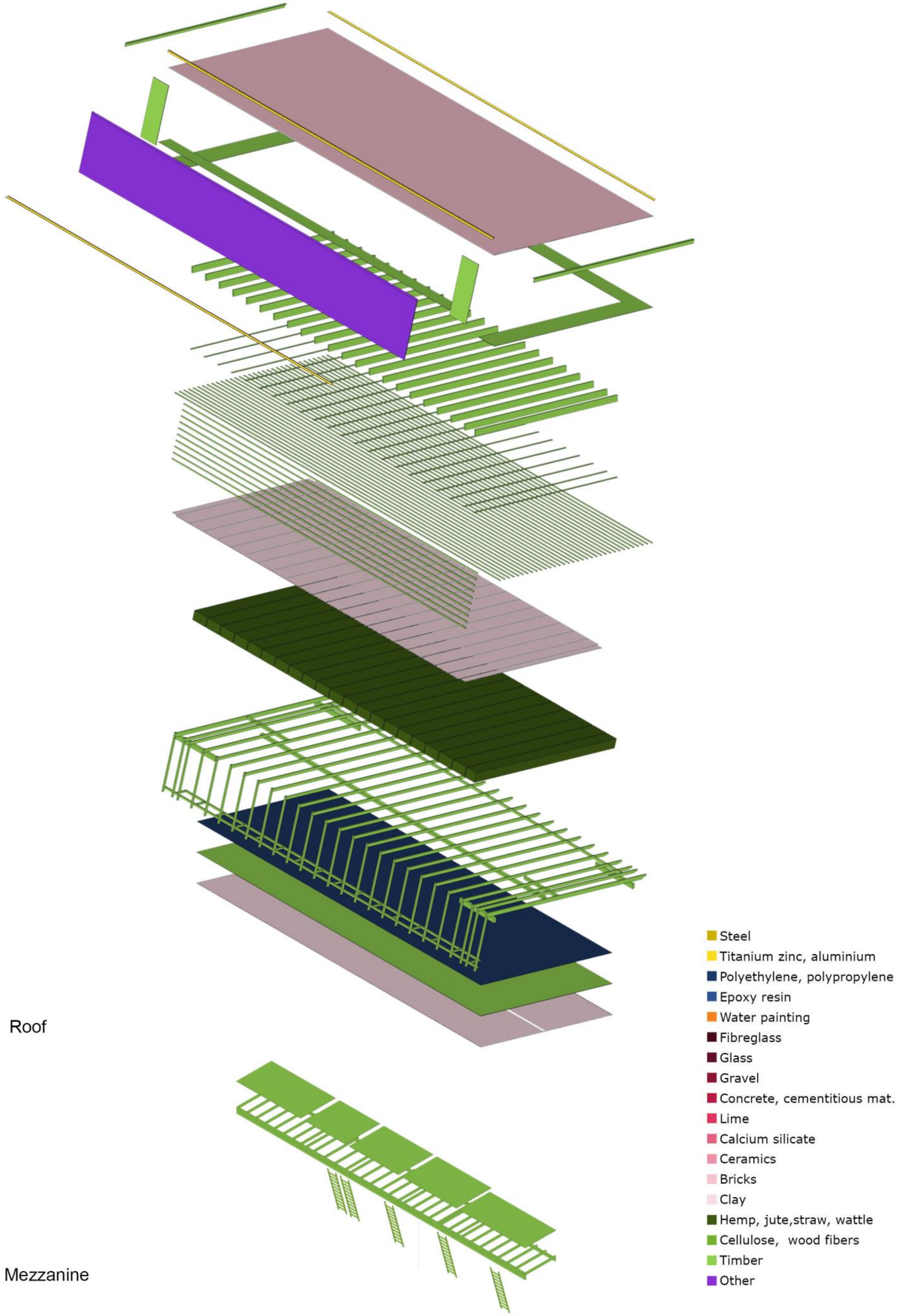
In all categories Sieben Linden reduced its Carbon Footprint since 2002. Energy and food footprint are respectively 36% lower, probably due to the higher number of residents sharing the facilities. Travel is also 19% lower.

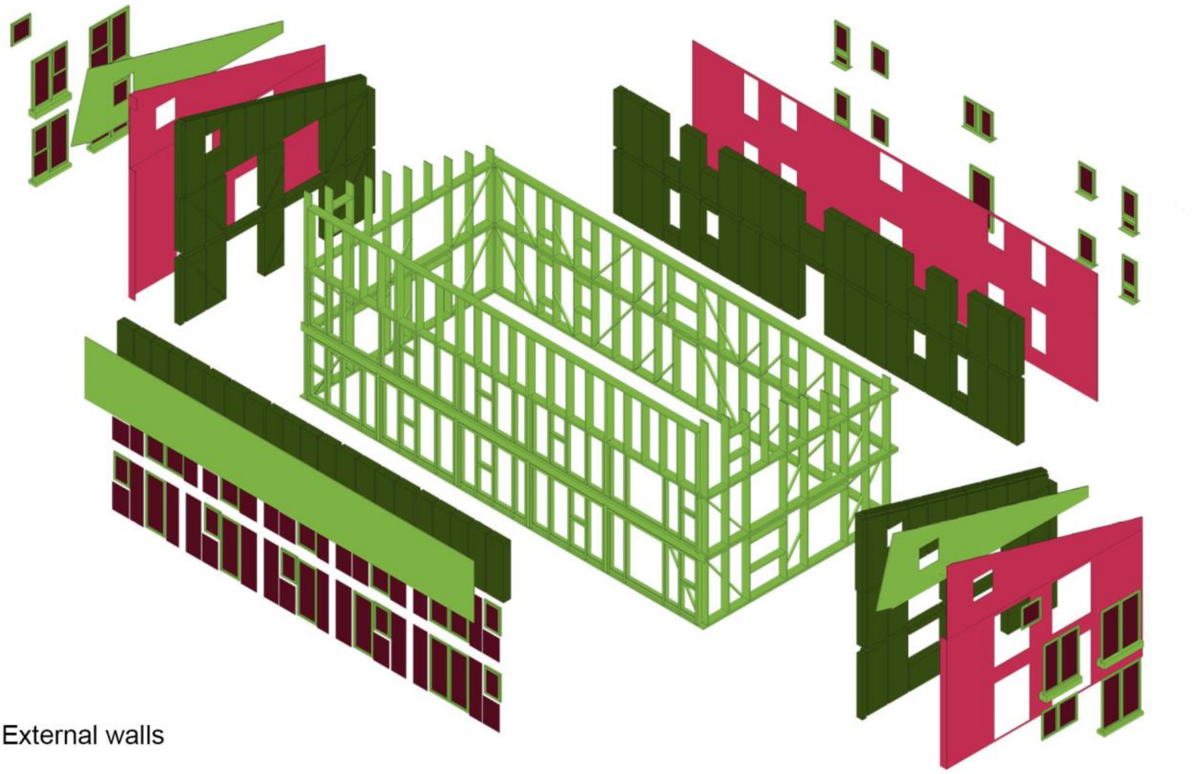
The overall recurring CF of Sieben Linden in 2014 is 25% lower than in 2002.

APPENDIX 3 – Libelle exploded axonometry




Partition walls of the first floor
Balcony
Interfloor
Steel
Titanium zinc, aluminium
Polyethylene, polypropylene
Epoxy resin
Water painting
Fibreglass
Glass
Gravel
Concrete, cementitious mat.
Lime
Calcium silicate
Ceramics
Bricks
Clay
Hemp, jute,straw, wattle
Cellulose, wood fibers
Timber
Other


Roof
Mezzanine
Steel
Titanium zinc, aluminium
Polyethylene, polypropylene
Epoxy resin
Water painting
Fibreglass
Glass
Gravel
Concrete, cementitious mat.
Lime
Calcium silicate
Ceramics
Bricks
Clay
Hemp, jute,straw, wattle
Cellulose, wood fibers
Timber
Other



External walls