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Screening LCA of clay plaster

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Introduction

Clay plaster is increasing in popularity as a building material in Swedish eco-building. The environmental impact involved in the activities connected to the making of clay plaster is the topic of this report and whether there are any certain steps in the life cycle that has a higher environmental impact than others, to what extent, and how they can be minimized.

Description of technical system

A flowchart of the system can be seen in *figure 1*. The grey squares in the figure shows areas of the model that are excepted from this study (1, 7, 8, 10, 20).

The clay plaster is a simple material made up of clay (binding), sand (aggregate), straw (reinforcing) and manure (easy handling, waterproofing). The variations of this setup is almost endless and will depend on the specific situation, application, availability of resources and other factors.

The material setup can differ but often all the functions will be included - something binding like clay(11), or subsoil mixed with clay, -an aggregate like sand(2) or soil, and -something reinforcing like straw(6) or hair. The manure(1) is mainly used to make the mix supple and easy to work with although it is also making the mix more resistant to weather and water, which is an issue when using clay mixes outdoors especially in wet climates like Sweden's. Water(10) is used to make the mix useful for most purposes.

Another common historical and modern day use of clay is masonry, and the mix will then only include clay and sand.

In this case, the clay mix will be used as a kind of plaster on the inner walls of an old log house as part of renovation. The mix used is normally measured in volume parts and looks like this;

1 clay
3 sand
1 straw
1 horse manure
1 rainwater

This plaster mix is used on the inside of the walls of the house directly onto the logs and will serve as the final wall layer and can be either painted or wallpapered. This serves about the same function as gypsum boards which is one of the most common building materials of inner walls in Sweden. However, the clay plaster has multiple functions; wind/drag stopping, moisture and heat buffering, and giving aesthetic value by the freedom of creating the texture and shapes that suits the user. It is also different from gypsum boards since it is smeared onto the wall into the desired thickness, thus it will not need perfectly even walls, as is important when working with board materials. The large moisture buffering capacity of the clay is another function that most other board material doesn't have.

The clay plaster is a typical passive product, where almost all the energy is used in the production phase of the life cycle. The expected lifetime for the clay plaster as it will be used and mixed in this case described above, is at least 100 years (Estimation by leading clay building expert Johannes Riesterer). An ideal and unique feature of clay mixtures is their ability to be reused. You can easily take down cracked or broken clay plasters, hundred years old from an old house, and use it as part of a new clay mix. This is due to that there is no chemical hardening happening in the material when using it as with cement and lime based plaster for example.

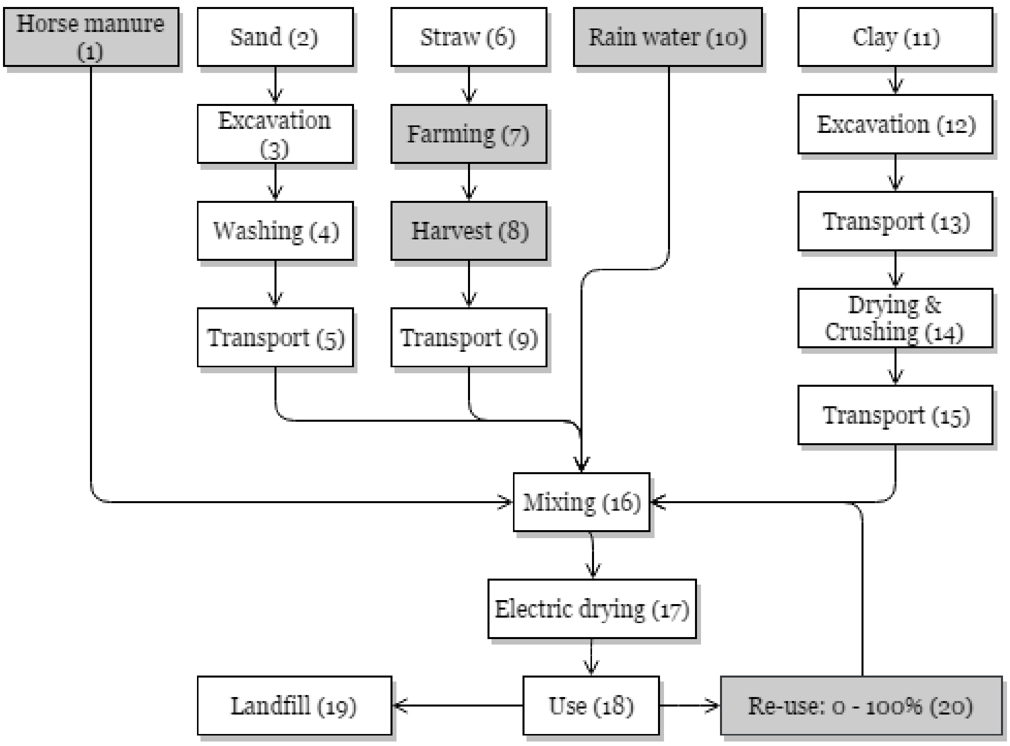

Figure 1 . *Technical system flowchart*

Method

This LCA is conducted in accordance with ISO 14040 and the work has been conducted according to *figure 2*.

The ISO 14040 working method means also that our working process, sources for calculations and other working methods are totally transparent for review. Methods for data collection, interpretation of results, analysis and impact assessment will be presented in respective sections. GWP is always in g CO_2 equivalents if nothing else is mentioned and based on 100 years (GWP-100).

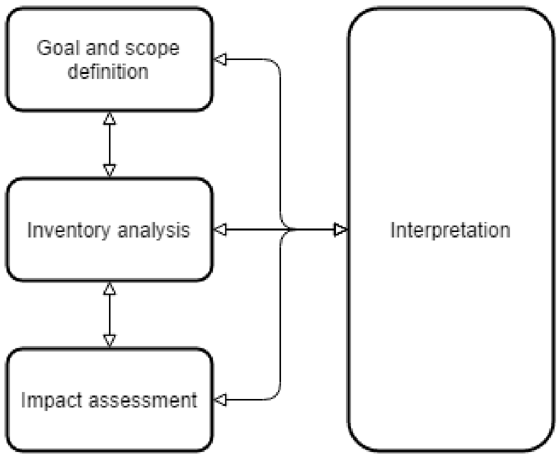

Figure 2. *Method flow chart.*

Functional unit

The functional unit is set as:

1 m^2 inner-wall plaster of 1 cm thickness.

In our case, the thickness of the plaster is about 3,5 cm, thus the calculations are multiplied with 3,5 in the end. This makes it easy to adjust the calculations for other situations. All calculations are shown for the F.U. (1 cm thickness).

Transports, excavation and electricity use stand for the main environmental impacts of this study. The same values are used for all types of transport, although since numbers are chosen from the highest source, the result will most likely be a maximum.

Goal and scope

The goal was to look at the different activities involved in making clay plaster, to see which of the activities has the highest environmental impact measured as Global Warming Potential (GWP-100) in CO_2 equivalents, and Acidification Potential (AP) in SO_2 equivalents. Comparing different alternatives in each step shows how the environmental impact can be affected (e.g. by taking clay locally, compared to transporting it to the site). The goal was also to make all the calculations as easily accessible as possible so that people who are in the situation of making clay plaster can put in their own numbers and re-do the calculations to see if there are any steps they might want to rethink to minimize their impact.
The clay plaster is then contrasted against gypsum board. The contrastation is done by looking at an American gypsum board LCA, to see about in what range of environmental impact they are compared to clay plaster.

Scope

This LCA has a cradle-to-grave approach, looking at the specific method of making clay plaster (see technical system). Figure 1 shows which aspects that have been measured and that are presented in the results. The grey squares shows materials that are not included in the mix (1, 7, 8, 10, 20) and are part of the discussion, but were not in the scope of being measured in our LCA. Horse manure is collected from the site and rainwater is collected providing the water needed, hence the environmental impact from these two resources are not expected to be of significance in this case. Waste handling is also expected to give minimum environmental impact and so this is also excluded from this LCA. Although, most of the clay plaster can be reused as mentioned earlier, in this LCA we have chosen to calculate assuming that all is going to landfill after use.
However, environmental impacts could be significantly reduced if reusing old plaster.

System boundaries

The chosen scope will naturally give a geographical boundary of the area where the materials for the mixture is retrieved. The building site lies in Hjärpalyckan, a small village in the south of Småland in Alvesta municipality. The sand comes from Olofsström in Blekinge and the clay comes from Bara outside Malmö. All other materials are locally collected (within 10 km). The time scope will for the functional unit be an estimated lifespan of the plaster as it is used for the inner wall of a log house - estimated to 100 years. The impact assessment will have a time span reasonable for measuring GWP - 100 years (*not connected to the lifetime of the plaster*). An overview of the product system is shown in *figure 1*.

Results

Sand

Speaking to the manager of Bröderna Björklunds Grus in Olofström, he explained that the natural sand that is used in our plaster is much less energy intense than using crushed rock, which requires the use of dynamite and large quantities of energy. However, he mentioned that natural sand is getting scarce and removing too much can threaten the groundwater since it works as a natural filter. This issue is already mentioned in other literature (Göransson SGU, 2015) hence we will not explain it in any depth, but in short the natural sands and gravels are actually our foremost groundwater reserves and since the societal demand on these materials keep increasing, it becomes a problem that threatens the Swedish environmental goal of groundwater quality. Many areas of use has been replaced by crushed stone the last decade, but in concrete making for example this does not work which means concrete making still use vast amounts of natural sand. The supply of sand and stone materials differ from region to region in Sweden and thus the most suitable choice of aggregate might depend on many factors. The manager of Björklunds Grus also mentioned that there are now operations making stonemeal out of waste stone from block-stone mines. This is apparently a material that earlier was just a waste product. As with all mining, there is much more waste than useful material, even when mining stone blocks, according to the manager. The environmental impact of that would therefore be less than normally crushed stone since the energy used for dynamite and excavation will partly be allocated to the block-stone.
Moreover it is possible to use crushed stone in clay mixtures according to clay builders spoken to, but this has not been confirmed in literature.

Clay

Clay can be found in the ground in many places in Sweden, although not everywhere. As can be seen in the following results, the excavation and handling of clay powder that can be bought is one of the most impacting processes in this clay plaster. Taking clay locally will reduce the impact of the clay process to just a small fraction, from 17,5% (85,8 g/FU) down to 2,1 % (8,8 g/FU) of total GWP. Although, the bought clay is less time consuming during the work process according to clay builders we talked to. This is due to the fact that clay found in the ground will often need time to soak before use and it might be contaminated with other materials which can affect the finished product in a negative way.

Straw

This LCA does not look deeper into the area of straw due to the fact that it could be considered a residue since no new land is required for its production. The straw is also a small part of the total mass flow as figure 3 illustrates. The environmental impacts from collecting the straw can be estimated in regards to the C sequestration loss in the wheat field compared to if the straw would have been left on the field or plowed down. But the total C sequestration should be higher if the straw is locked in the wall for 100 years. When removing the straw there will also be a need to add extra nutrients as a compensation. Changes in leaching due to straw removal will also have to be considered for the full picture. Due to its complexity and need for complete comparison with other structure giving materials for the clay mixture only some technical values are given here to give a view of the size of the impacts.

Baling and Handling of one ton of wheat straw requires 61 MJ. The total GWP is 135.49 kg CO2-eq. The portion coming from straw removal (Soil C related) is 118.14 kg CO2-eq and the part from fertilisers compensation is 17.34 CO2-eq. (R. Parajuli, 2013)

Life cycle inventory and impact assessment (LCI, LCIA)

The LCI is presented in *table 1*, LCIA in *table 2* and mass flow of processes in *figure 3*.

Processes	Process needs	Source for process needs	Data used
Clay			
Excavation	0,1 h / ton Volvo L120E 164 kW and Catepillar D8	Personal communication Bara Mineraler + Database	Since numbers were unsure and hard to get from primary source, we have uesd databases to complete calculations (see appendix)
Transport	18 km. 40 ton / lorry	Personal communication Bara Mineraler	Rydh, Lindahl, Tingström have been used as source for calculations
Drying/crushing	150 kWh electricity / ton	Personal communication Bara Mineraler	LCA from Vattenfall on Nordic energy mix
Transport	198 km single lorry / 3 ton	Info from our situation	All transports have used the same calculations
Sand			
Excavation	4 dl Diesel / ton sand	Personal communication Bröderna Björklunds grus	Same as for the clay has been used to simplify work process
Washing	60 ton / h. 120 kW electric washer = 2 kWh/ ton	Personal communication Bröderna Björklunds grus	LCA from Vattenfall on Nordic energy mix
Loading	2 min / 30 ton. 20 L diesel / hour = 0,0022 L / ton	Personal communication Bröderna Björklunds grus	Negligable - not used in our LCIA
Transport	60 km single trailer = 12 ton	Info from our situation	All transports have used the same calculations
Straw			
Farming			No information found. See discussion
Harvesting			No information found. See discussion
Transport	10 km Tractor		All transports have used the same calculations
Mixing	20 min / 180 L plaster 3,5 kW blender = 1,17 kWh /180 L = 0,09 kWh / F.U. (10 L)	Info from our situation	LCA from Vattenfall on Nordic energy mix
Drying on wall	drying fan 1000W and dehumidifier 250 W = 1 250 W. Estimated drying 5 h / F.U. = 6,25 kWh / F.U.	Info from our situation	LCA from Vattenfall on Nordic energy mix

Table 1. *This shows the initial inventory. Most process needs are primary data. The actual method of calculating the result for each flow is shown in the column of data use. Results are shown in table 2. For calculations see appendix 1. For detailed references, see references.*

Unit process	GWP CO2e g/ton	AP SO2e g/ton	Mass need (kg) / F.U.	GWP / F.U	AP / F.U.
Clay:	**22012,6000**	**250,3870**	3,9000	85,8491	21,4955
Excavation	2261,2000	178,1920			
Transport to factory	997,2000	5,9400			
Drying crushing	7785,0000	0,9150			
Transport to buidling site	10969,2000	65,3400			
Sand:	**5689,0000**	**198,0042**	**13,5000**	76,8015	15,2070
Excavation	2261,2000	178,1920			
Washing	103,8000	0,0122			
Loading					
Transport	3324,0000	19,8000			
Straw:	**554,0000**	**3,3000**	**0,0840**	0,0465	0,0002
Transport	554,0000	3,3000			
Other processes:					
Mixing				4,6710	0,0005
Drying				324,3750	0,0381
Total:				**491,7432**	**36,7414**

Table 2. *Shows resulting calculations. For detailed calculations, see appendix 1.*

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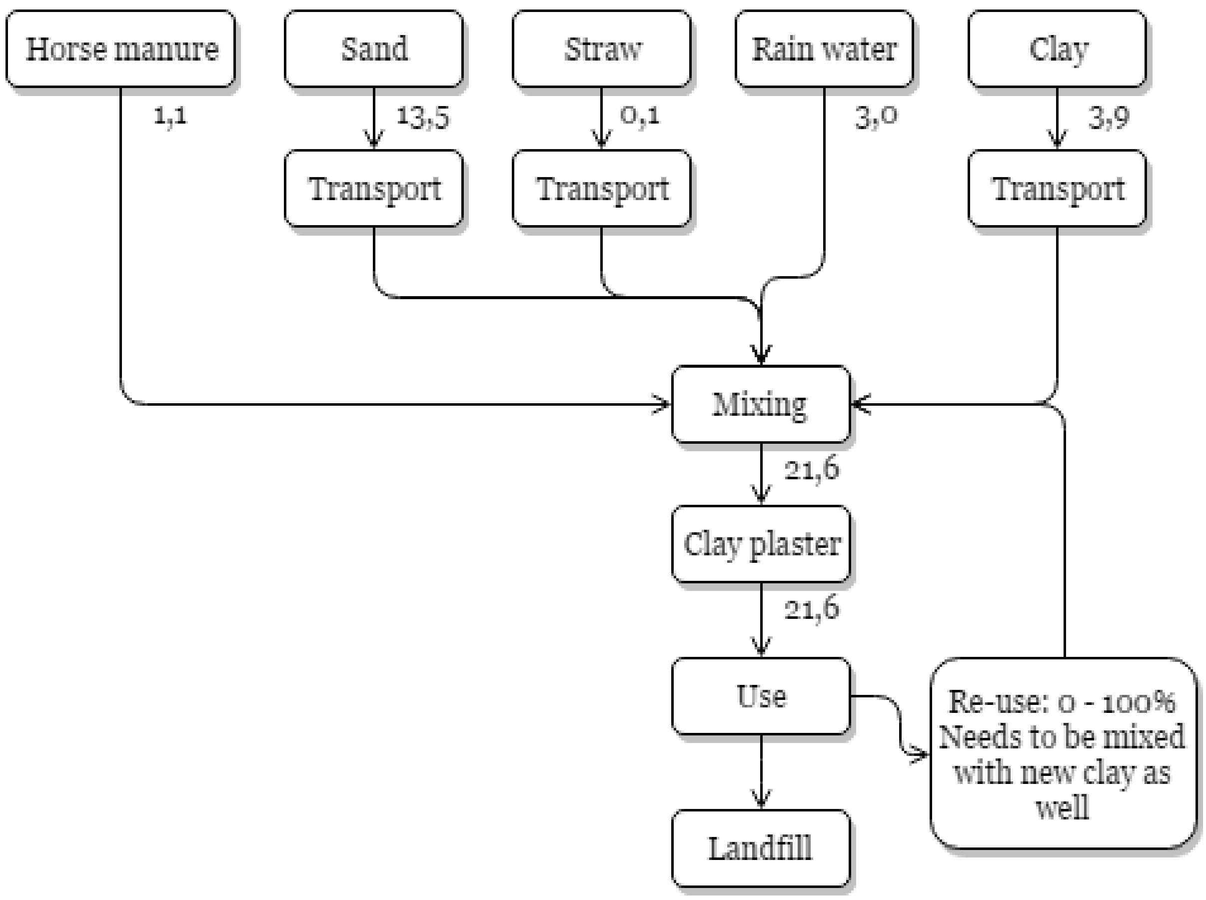

Figure 3. *Mass balance (kg) for 1 F.U. (1 m² wall of 1 cm thickness)*

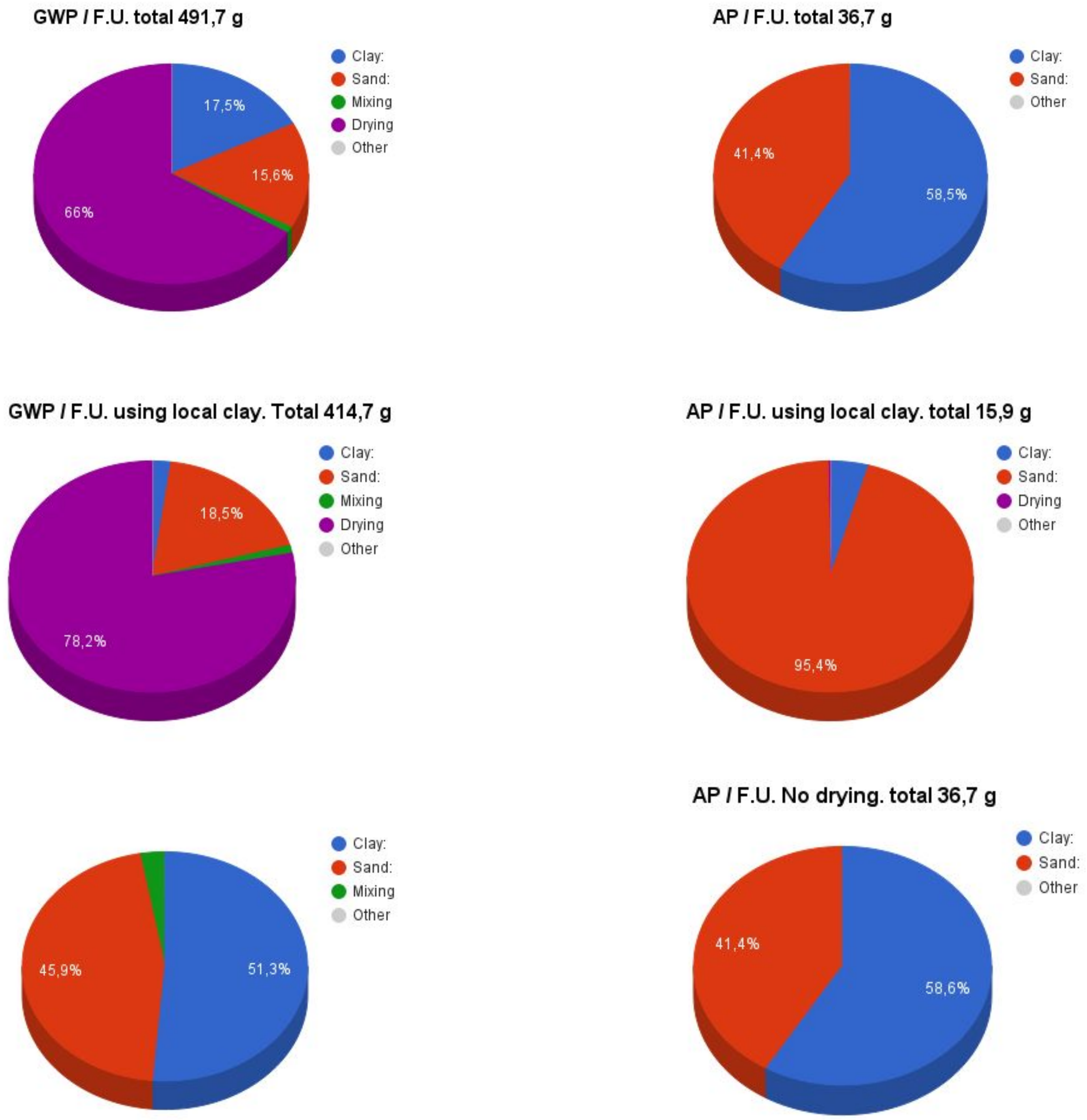

Figure 4. *Top: Part of environmental impact if drying, counting on drying 9 m² in 48 hours using a 1000 W fan and a 250 W dehumidifier. This is a rough estimation but is expected to be an absolute maximum of drying time. It should also be observed that no drying at all might be possible in summer time and it would then be enough with a blowing fan and open windows. Middle: Using local clay. Bottom: No drying and using local clay, counting only the excavation step in the clay process system as if digging the clay in your own backyard, which is sometimes possible.*

Contrasting against gypsum board

To contrast clay plaster against gypsum board an LCA study of gypsum board is used (Gypsum Association, 2013,) and from that calculated the GWP / F.U. which was the only comparable variable available in the study. The comparison is shown in *figure 5*. We used the product called ½" regular GWB in the study and recalculated it into our F.U. (see calculations in appendix).

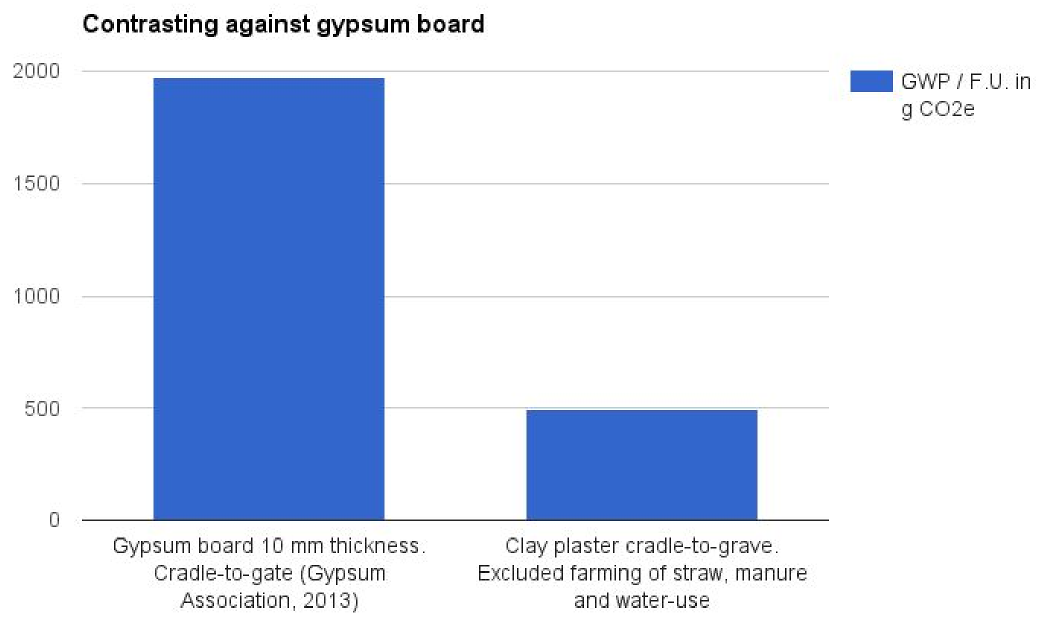

Figure 5. *In the clay plaster, all the processes that have been described earlier are included. The gypsum LCA used a cradle-to-gate perspective which means that the difference would be even higher if we included transports to the building site. The electricity production used for producing the gypsum is coal here which means that the gypsum production might have a significantly lower GWP if produced with another energy production method. Observe; that this is just a contrasting comparison, thus no conclusions can be drawn from the figure without further research.*

Gypsum board is mostly put to landfill after being used which also risks other environmental problems such as sulphur leakage. Although, the potential of re-use and recycling has lately been paid attention to (Johnsson, 2013).

Discussion

Sand

Things to consider with sand is, as we have mentioned, what kind of sand to use as we have gotten indications that using crushed rock wastes from stone-block mining might be an alternative. Although, further research on the topic is necessary to make any conclusions.

Clay

Using local clay could reduce environmental impact, although the bought clay is easier to work with and might many times be the only alternative.

Manure

Manure was not included in this study, however, when using manure the transport will probably be the most impacting process hence local materials should be used. Manure is also not necessary in most cases.

Water

Water used in our plaster was collected rainwater and therefore it had no emissions or environmental impacts of magnitude. However, using fresh water will most likely require a pump and then that energy will be of concern although estimated to be a minimal amount of energy compared to the other elements in the process.

Straw

From the point of view of the farmland, considering the GWP it's better to leave the straw and not use it in the clay plaster mixture. But then the mixture would need a substituting material giving it structure and that would have to be compared with straw. This field needs more study as one articulation of sustainable development is not sufficient to draw conclusions from.

It would also be interesting to compare other materials to straw, maybe there are waste products that are as suitable for use. If production were to be scaled up, this consideration would be important.

Drying

The drying process is both the biggest contributor to GWP and the most uncertain data part in our analysis. Since only electricity is used for drying in our (vague) estimation, GWP is the most concerning environmental aspect compared to AP which due to the nordic energy production is very low. Since the drying seems to be a potential high number in GWP, that is also an area of interest to look further into for substitution when trying to minimize the environmental impact.

Contrasting to gypsum

The comparison to gypsum board seems to show that this clay mix is a much more energy efficient material under the given circumstances and system boarders. Although interesting, no conclusions can be made on such simple comparisons without researching further and making a complete comparing LCIA. The gypsum LCA is based on an electricity production by coal which makes the comparison even less comparable since the clay is based on the nordic energy mix. Both materials can be reused, although it´s far from always the case with gypsum which risks leaching sulphur when put to landfill. The two materials are also not perfectly comparable in terms of functionality, see introduction.

Big scale use

Would clay boards be a good alternative to gypsum board?
From a waste perspective we think that the answer is definitely yes, if the clay mix is kept clean from toxic chemicals in production, since the clay mix is harmless to the environment while gypsum tend to leak sulphur. Although recycling and re-use practices are available for both materials which also has to be considered.
There are of course a multitude of other things to take into account hence a complete study is necessary to answer the question.

One of the interesting things is the reinforcing materials used. Using straw for this might be okay if the straw would otherwise wither away where it is not of use. But in many cases it might be better to leave the straw on the field as mentioned.
We would also have to look at how to get enough rock meal in a good way. And of course, look at how much clay we can take from the earth crust in a sustainable way.

Conclusions

Most energy use and environmental impact making clay plaster in this way, comes from the extraction of sand and clay and the transport of materials to the building site. If one is to minimize the impact when making clay plaster, one should consider if it is possible to get clay locally. When it comes to sand, we only looked at natural sand 0-2 mm normally used for masonry. It is possible to use crushed stone which demands more energy but does not pose the same threat to groundwater as taking natural sand. The drying process should be investigated further since our approximation of time and energy is not measured, but only estimated. However we can conclude that it should preferably be done without electrical heating if possible and it is a clear sign that the drying should be taken into consideration when using clay plaster.

References

Litterature

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Rydh, C. J., Lindahl, M., Tingström, J.. Livscykelanalys - en metod för miljöbedömning av produkter och tjänster. (2002). Studentlitteratur.

Vattenfall. Livscykelanalys. Vattenfalls elproduktion i norden. (2012).

Database

ELCD database 2.0, from web 2016-12-16:
http://eplca.jrc.ec.europa.eu/ELCD3/datasetdetail/process.xhtml?uuid=9e6d3b0e-cb47-4df3-969b-f23a75a0ae42&version=03.00.000&stock=default

APPENDIX

Table 1						
Clay excavation			**g per ton**	**GWP CO2 eq. g / ton**	**AP SO2 eq. g/ton**	**Source**
CH4_h	1,12	g CH4/h at full load	0,112	2,8		http://eplca.jrc.ec.europa.eu/ ELCD database 2.0
CO_h	150,00	g CO/h at full load	15	45		http://eplca.jrc.ec.europa.eu/ ELCD database 2.0
N2O_h	3,00	g N2O/h at full load	0,3	89,4		http://eplca.jrc.ec.europa.eu/ ELCD database 2.0
NMVOC_h	29,00	g NMVOC/h at full load	2,9			http://eplca.jrc.ec.europa.eu/ ELCD database 2.0
NOx_h	520,00	g NOx/h at full load	52	364	36,192	http://eplca.jrc.ec.europa.eu/ ELCD database 2.0
SO2_h	1,42	kg SO2/h at full load	142		142	http://eplca.jrc.ec.europa.eu/ ELCD database 2.0
CO2		kg CO2/ton	1760	1760		Calculation
Total				2261,2	178,192	

Table 2		
GWP-100 [g CO2 eq/g]	**Factor**	**Source**
CH4	25	https://www.ipcc.ch/publications_and_data/ar4/wg1/en/ch2s2-10-2.html
N20	298	https://www.ipcc.ch/publications_and_data/ar4/wg1/en/ch2s2-10-2.html
NOx	7	Rydh, Lindahl, Tingström
AP [g SO2 eq/g]		
SO2, SOx	1	Rydh, Lindahl, Tingström
NOx	0,696	Rydh, Lindahl, Tingström
NH3	1,88	Rydh, Lindahl, Tingström

http://eplca.jrc.ec.europa.eu/ELCD3/datasetdetail/process.xhtml?uuid=9e6d3b0e-cb47-4df3-969b-f23a75a0ae42&version=03.00.000&stock=default

Diesel consumption excavation	0,55	kg /ton					http://eplca.jrc.ec.europa.eu/ ELCD database 2.0
Emission	3,2	kg CO2/kg diesel					http://www.engineeringtoolbox.com/co2-emission-fuels-d_1085.html
Emission / ton	1,76	kg CO2/ton clay					Calculation
Transport to factory km	18	km	55,4	g/tkm CO2 eq	997,2	g CO2 eq / ton	Rydh, Lindahl, Tingström
Transport to factory km	18	km	0,33	g/tkm SO2 eq	5,94	g SO2 eq / ton	Rydh, Lindahl, Tingström
Drying crushing clay	150	kWh	51,9	g CO2eq/kWh	7785	g CO2 eq / ton	Vattenfall LCA
Drying crushing clay	150	kWh	0,0061	g SO2eq/kWh	0,915	g SO2 eq / ton	Vattenfall LCA
Transport to building	198	km	55,4	g/tkm CO2 eq	10969,2	g CO2 eq / ton	Rydh, Lindahl, Tingström
Transport to building	198	km	0,33	g/tkm SO2 eq	65,34	g SO2 eq / ton	Rydh, Lindahl, Tingström

Process	**km transport**	**el.: kWh/ton**	**g CO2e/kWh,tkm**	**g SO2e/kWh, tkm**	**g CO2 e / ton**	**g SO2 e / ton**	
SAND:							
Washing		2	51,9	0,0061	103,8	0,0122	Vattenfall LCA
Transport to building	60		55,4	0,33	3324	19,8	
STRAW:							
Transport to building	10		55,4	0,33	554	3,3	
Farming							
Harvesting							
		el.:kWh/F.U			**g CO2 e / F.U.**	**g SO2 e / F.U.**	
MIXING		0,09	51,9	0,0061	4,671	0,000549	
DRYING		6,25	51,9	0,0061	324,375	0,038125	