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Carbon storage technologies applied to rethinking building construction and carbon emissions

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Abstract. This study has been conducted to offer an insight into the prospect of the building industry decarbonization. The paper aims to analyze the carbon impact of material production, transportation, and construction phases from the construction site perspective in the first section. The focus was on modern alternatives that would allow engineers to include Carbon Capture and Storage (CCS) technologies that could meet the expectations and eventually be a reliable alternative to sustainable economic development. One of the main reasons for climate change is the increasing concentrations of Greenhouse Gases (GHG). There are two ways to reduce the GHG emissions in the atmosphere: first, reducing directly and voluntarily the emissions by stopping polluting activities, second, by capturing and storing the emissions. Among the findings, the first proposed solution was decreasing the reliance on fossil carbon; the second proposed alternative, CCS, is more related to reduce CO_2 emissions from energy and other energy-intensive sectors. The formulas and calculations of the Life Cycle Assessment (LCA) were applied in a case study. Technical solutions should be accompanied by legal regulations and policies, socio-cultural considerations. This paper expects to raise the awareness of the readers of the construction sectors related to their GHG emissions participation.

Keywords: CCS, Building sector, GHG, LCA, Environmental assessment.

1. Introduction

Climate change, driven by anthropogenic greenhouse gas (GHG) emissions, remains one of the most urgent global challenges. The 2015 Paris Agreement established a global action plan of limiting global warming to well below 2 °C above pre-industrial levels and to make best efforts to limit this increase to 1.5 °C [1]. To achieve this goal, governments, industries, communities and individuals must incorporate significant changes at all levels and in all activities, especially those with a significant carbon footprint [2].

The construction industry is one of the largest sources of carbon dioxide generation, energy consumption, and pollutant emissions [3], ranging from collection, transportation, and manufacturing of building materials to operation, so adopting approaches toward carbon neutral or carbon negative by 2030 may be answered for the construction sector and climate change [4].

One opportunity to improve environmental impacts and GHG emission reductions in the construction sector is to adopt carbon capture and storage (CCS) technologies in some of the phases. Such systems allow separating CO_2 generated in anthropogenic transformations that use fossil combustion to generate energy and then store it in places where CO_2 does not come into contact with the atmosphere [5].

For this study, it was used data from the construction of the main administrative building located in Seraing city, Belgium-Europe. The Government has published the data to guarantee the environmental sustainability of the project. The study aims to precise and study the environmental impact of the project construction and establish the possible anticipate the environmental impact of the construction site itself through the production stage of construction.

Climate change's burning issue compelled us to rethink people habits and lifestyle to achieve an accurate understanding of environmental responsibility. Nevertheless, how could a tailored and robust strategy achieve carbon emissions' ambitions if researchers cannot account, enumerate, and quantify them? For all these reasons, the LCA method has become a game-changer tool for climate change responses [6]. Indeed, by identifying essential materials and building consensus, LCA is today indispensable for thinking about tomorrow's building. When using the LCA tool, practitioners should try to define the goal of the work: whether to compare, to deal with eco-conception, or to declare its carbon emissions. This paper aims to calculate and compare the carbon emissions to explore the carbon source and key emissions factors.

LCA considers all the steps from the extraction of raw material to their end of life to meet the expectations. Strengths of this method are doubled: first, one can have a good indicator of the weight of one product not only while used but also before and after it is needed, second it gives a single number allowing easy comparison with different designs for one building or different buildings through the prism of carbon footprint. The different stages of the building sector based on an LCA approach are presented in Figure 1; these stages consider the following phases: production, construction, use, end-of-life, benefits-after-used [7].

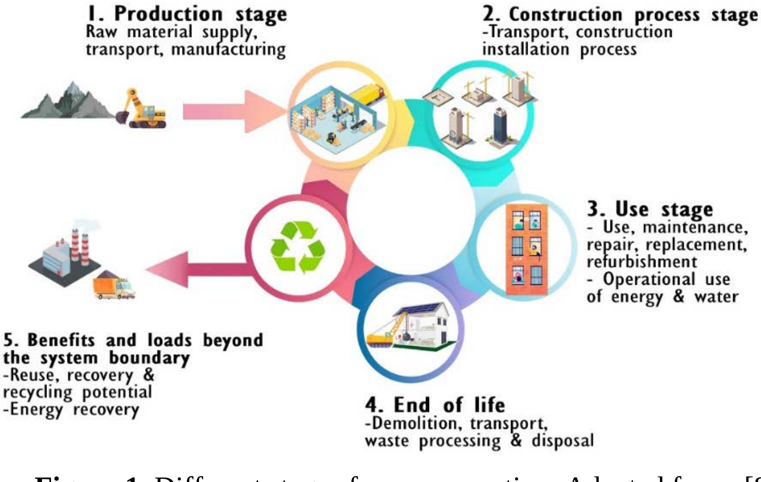

Figure 1. Different stages for one operation. Adapted from: [8]

It is essential to realize that LCA has been created to anticipate the numerous uncontrollable factors making the total accounting approximate. The authors will regroup the two first phases and the two last phases to end up with three phases. Those three main phases are the ones with a significant potential for decarbonization.

2. Calculation Models and Methods

Eventually comes the trickiest step: the inventory of products on its way in and out of the operation (Table 1). It was made a strategic choice and only focused on the main and the most significant building component. To be more accurate, one category 'others' was added, accounting for around 20% of the final CO_2 emissions, representing everything it was overlooked.

Table 1. Inventory analysis of raw materials for building structures

CONCRETE	Mass total		Volume weight	Emission factor	Carbon Emission
	m^3	ton	kg/ m^3	kg eq CO_2/t	t eq CO_2
	2315	4863	2100	367	1785

STEEL	Mass	Emission factor	Carbon Emission
	ton	kg eq CO_2/t	t eq CO_2
Frame	273	3190	871
	Surface	Emission factor	Carbon Emission steel
	m²	Kg eq CO_2/ m² (wall)	kg eq CO_2/t
Coating	3000	7.81	23.4
Total			894.7

GLAZING	Square footage	Emission factor	Carbon Emission
	m²	Kg eq CO_2/t	t eq CO_2
Outdoor	568	59	33.6
Indoor	351	32.8	11.5
Total			45.1

INSULATION	Side	Volume weight	Mass	Emission factor	Carbon Emission
	m^3	kg/ m^3	kg	kg eq CO_2/kg	t eq CO_2
Polyurethane	64	40	2548	6.79	17.3
Stone wool	964	70		1.09	73.5

After one could determine first the contribution of carbon source emission in the whole process of the building and the total amount of carbon emissions, then the interpretation of results first highlights the top key factors that affect the total carbon emission. Then it studies their reliability and the possibility of their replacement.

Unsurprisingly, a building's total carbon emissions are the sum of its carbon emissions during the three previously established processes. It can be summarized in a first equation

$$E = E_p + E_t + E_c \quad (1)$$

E represents the total carbon emissions of the whole building construction process, Ep, Et, and Ec, representing the carbon emissions generated during the production stage, transportation stage, and construction stage. It is frequently chosen to neglect the human labour and the different shifts on the machine, responsible for carbon emissions to small compared to emissions from energy consumption and raw materials.

Controlling the eco-conception of the operations means controlling E. Therefore Ep, Et, and Ec were determined.

2.1 Carbon emissions during the Production stage (E_p)

During the production stage, carbon emissions are being generated by both the raw materials stated in the inventory and the energy needed for that equipment. To sum up, Ep will gather, during the production process

- The consumed: raw material C_{pm} , fuel oil C_{pf}, electricity C_{pe}, factors I C_i
- The carbon emission factors of raw material F_m, fuel oil F_f, electricity F_e , factors i F_i

In the following equation

$$Ep = C_{pm} \times F_m + C_{pf} \times F_f + C_{pe} \times F_e + \sum_i C_i \times F_i \quad (2)$$

2.2 Carbon emission during the Transportation Stage (E_t)

To transport all our materials from the location, they are extracted to the construction site. It is needed transport vehicles their selves needing fuel oil, fuel oil releasing GHGs. It is constantly considered vehicles to be fully loaded (even though they should be empty on their way back). Eventually, Et will take into account:

- The number of vehicles needed to transport the merchandise called n
- the carbon emission factors of energy consumption of vehicles F_q
- the fuel consumption when the transport vehicle is fully loaded C_f
- the distance from the prefabricated plant to the construction site,

In the following equation

$$\text{Et} = \sum_{i=1}^{2n} F_q \times C_f \times D \quad (3)$$

2.3 Carbon emission during the construction stage (E_c)

It was taken into account the need for the energy consumption of the machine. Eventually, Ec: will take into account:

- The consumption of fuel C_{cf} and electricity C_{ce}
- The carbon emission factors of fuel F_f and electricity F_e

In the following equation:

$$\text{Ec} = C_{cf} \times F_f + C_{ce} \times F_e \quad (4)$$

3. Study Case on Belgium building

The administrative building in Lille has 6345 m^2 of public space, at the government expenses. Materials came from a range of a maximum of 30 km around the city of Seraing, so authors homogenously consider that vehicles are always travelling for 60km round trip. Concerning transportation, we will consider one type of vehicle with a maximum load of 40t per trailer and fuel consumption of 45L/100km. Concerning the raw materials extracted and synthesized in the inventory, it is approximately 3400-ton equivalent CO_2. Nevertheless, each materiel has a different weight in this amount, described here:

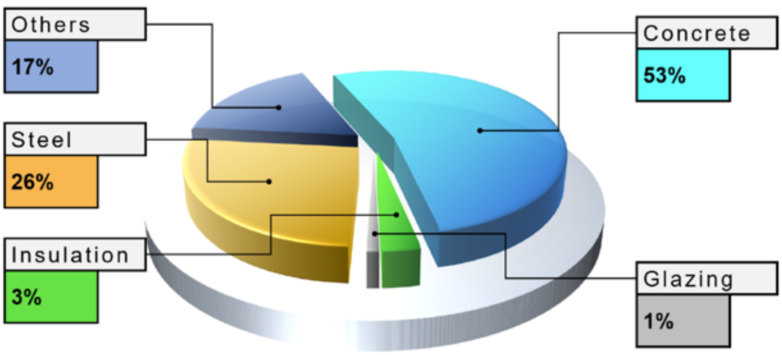

Figure 2. Environmental loads of the different materials used.

Regards the emission factors used in this study, it is listed as follows in kg eq CO_2/kg: Fuel (coal) =2.00, electric energy = 0.928, Fuel (oil) = 2.730, considering total conversion of 100 kWh equals to

23.314 kgCO_2-eq. These emission factors were applied in order to obtain the relative contribution of the components based on a standardized unit (kg eq CO_2/kg), being the concrete and steel the predominant ones, with 53% and 26%, respectively.

The production stage includes the amount of GHG emissions associated with the mining, processing, and production of construction materials. The mechanical equipment consumes energy such as electricity, coal, and fuel oil and is directed by human labour. The values of the corresponding categories are depicted in table 2.

Table 2. Material and energy during the production stage

Item	Such as	Total power	Unit	Carbon Emission Factors kg eq CO_2/kg	Carbon emissions T eq CO_2
Raw material	Concrete				3400.00
	Glazing				
	Steel				
	Insolation				
Labor		500	hours	0.645	0.323
oil-burning boiler	steam maintenance	1 000	kWh	23.314	4.29
electric trucks	hoisting and stacking concrete pouring, cutting the bars and removing the mold	5000	kWh	23.314	21.45
Total					***Ep* = 3426.17**

Concerning the production phase in this case study, the amount of CO_2 emissions was the highest for concrete, followed by a steel structure. The percentage of CO_2 emissions of these materials constituted 79% of total emissions from production. This percentage is similar to most studies, which is why it is relevant to conclude from our experiments. The extraction of natural resources is a lot responsible for the scarcity of non-renewable resources and the large amount of energy (fossil fuel) consumed and, eventually, many air-pollutants. Therefore, concrete and steel are two materials that could have an outrageous impact on CO_2 reductions if alternatives were to be found.

4. CCS technologies' application in the construction industry: a reliable solution for climate change?

To deal with climate change, scientists studied and developed several technologies to capture and store and GHG due to their vast growth in recent years. In order to mitigate climate change in the building sector, some ideas are presented: designing buildings based on low-energy consumption, integrating renewable energy technologies as well as storing carbon emission, etc [9]. Moreover, in the manufacturing sector, some strategies are proposed, such as: consider a data analysis, looking for the most extensive energy-consuming stage and material, then reducing its environmental load, for instances, consider the option of a solar plant on the roof buildings [10].

The delimitation of this study scope focuses on showing the potential for the buildings sector to achieve zero GHG emissions and even negative emissions. The short-term impact of large-scale GHG reductions from the use of carbon-storing materials has proved to be worthy of consideration for the building sector and policymakers.

Among the incentives for carbon storage, capturing carbon into rocks could be a reliable alternative to deal with the emissions although the transport cost of the rocks. However, carbon-sequestered rock can be manufactured in the construction centres, which reduces its main drawback, transportation. In this context, the principal benefit is that once carbon has been captured and stored in rocks, it is stable and hard to release. This product might persist for millions of years since it only can be broken when heated up to 700 °C or by dissolution in strong acid, resulting in a promising alternative.

To date, the cement-industry represents around 6% of all carbon emissions, and around 4.1 Gton are released annually. Cement CCS are the technologies used to capture the generated CO_2. In cement production, CO_2 is released by these processes: combustion of fossil fuels as coal (40%), raw material transportation and electricity generation (10%), and 50% during decomposition of $CaCO_3$ to CaO, which is the crucial component of cement according to the equation $CaCO_3 \rightarrow CaO + CO_2$. Cement can be made for absorbing carbon quickly: for example, substituting the conventional binding material, which is used in cement, with MgO. Another way to store carbon is by combining calcium with flue gas, creating a calcium carbonate and locking the carbon.

In the UK, Manchester, a chemistry start-up called Econic Technologies, is working on the way to store carbon in polyurethane foams. Polyurethane foams can be used in furniture upholstery, car seats, mattresses, and particularly for housing insulation. The innovation component consists of: using CO_2 emissions, helping for polymer's production and creation a form for insulation, which is eco-friendly and cheaper. This strategy might save the equivalent of taking two million cars off the road if applied worldwide.

Switching to fossil-free fuels offers a decrease in the carbon footprint of CLT, a fact that is mainly related to the Sustainable Development Goal (SDG) 7, 9 and 15 [11]. The technology to convert carbon emissions and recycle them into synthetic natural gas has been developed for a long time. However, the process is energy-intensive and expensive. In 2017, researchers at the US Department of Energy proposed innovative methods to treat carbon as fuel much quicker and easier, saving energy. They dissolve the CO_2 in water, which needs high temperatures and manage the transformation at room temperature using specialized liquid materials. Moreover, the circular economy application in the construction sector is taking advantage in the present, for example, features as the robustness of materials, reversibility of the structure, maintenance techniques, reuse scenarios [12]. Finally, the industries have challenges in the environmental, economic and energetic sectors to evaluate their impacts and propose practical projects to improve their performance [6] since there is a need to quantify the effect of large quantities of raw materials and resources on the most of the industries before deciding on best practises in energy conservation, usage of alternate fuels, and the use of CCS [13].

5. Conclusion

The construction industry is a crucial sector for the ecological transition because of carbon emissions. LCA is increasingly being used to determine the impact of building construction. This paper was applied to a real study of the concept of the evaluation system of carbon emissions. Among the findings, the construction sector is responsible for more than 4000 tons of GHG emissions, mainly due to the production stage. Transformational change is needed if the industry achieves a low carbon-built environment and plays its part in reaching France's 2050 net-zero target. The results highlight the importance of intensifying efforts to identify and manage carbon emissions and the importance of simultaneously acting now by implementing available measures (material substitutions, changes of cement) while actively planning for long-term measures (regulations, carbon taxes, sanctions).

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