Construction CO_2
How much, where from, and how to get rid of it?

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I am concerned. Temperatures are rising, and we are running short on resources. Something's gotta give. But we find it hard to make the required changes. We find it difficult to comprehend what "the required changes" means. We find it complex to understand where our troubles begin. Where do the carbon dioxide emissions causing us so much hardship come from? Let's find out. And let's focus on a sector we can all relate to, a sector that is responsible for a substantial share of global CO_2 emissions, a sector that needs to step up and improve. Let's focus on Construction.

The construction sector at a glance

The construction sector delivers houses, apartments, stores, offices, schools, hospitals, factories, roads, bridges, etc. to our societies. It is one of the largest sectors in the world, employing 7% of the world's working population and contributing 13% of global GDP [MCK2017]. Construction projects are categorized as residential, commercial/institutional, industrial, or infrastructure [NIST2009], but that's just a detail. Let's stay focused on the bigger picture.

Perhaps due to its fragmented nature, where incentives among owners and contractors are often misaligned, and complexity (and opacity) across the value chain makes joint improvement initiatives difficult, the construction sector is underperforming. Its labor productivity, for example, has increased by a mere 1% annually over several decades, lagging significantly behind the overall economy (2.8%) in general and the manufacturing sector (3.6%) in particular [MCK2017].

In Northern Europe (Denmark, Germany, Netherlands, Sweden, UK), the annual productivity increase has been in the 0-1% region with Belgium standing out at around 2% productivity increase and the highest productivity of all. In Southern Europe (Italy, France, Portugal, Spain), productivity has *de*creased by 0-1% annually. The same is true for the USA, where labor productivity is today around the same level as in the 1960's. In Eastern Europe, higher productivity improvements (from a lower baseline) are generally observed [MCK2017].

Construction is a big and important sector, but one that does not perform as well as could and should be expected. A lot of people are doing a lot of good work, but it somehow does not add up to what is needed. (performance benchmarking is the solution, but we will get to that later)

CO_2 and other greenhouse gasses

We humans release around 54 Gt of carbon dioxide into the atmosphere every year [UNE2018]. That is: 54,000,000,000,000 kilograms of CO_2. It's a lot. And to be precise, it's actually 54 Gt of *greenhouse gases* measured in units of CO_2 equivalent, that is the amount of CO_2 that would have to be emitted to have a similar (negative) effect on global warming.

Around 77% of these greenhouse gas emissions actually come in the form of CO_2, while an additional 15% is methane (CH_4), 7% is nitrous oxide (N_2O), and the remaining 1% is so-called F-gases (HFCs, PFCs, SF_6), which have global warming potential (GWP) thousands of times higher than CO_2 [WRI2009,DEPA2012].

Approximately 25% of emissions stem from electricity and heat generation, and other high-emission sources include industrial energy use (14%), transportation (14%), and agriculture (14%) [WRI2009].

But how much of this can be contributed to Construction? How much electricity is used in the construction sector, how much energy is used in factories to produce buildings materials, and how much fuel is burned to transport materials and workers to site?

Emissions from the construction sector

Allocating CO_2 emissions to the construction sector is not trivial. And regional differences in Construction CO_2 emissions exist, driven – for example – by regional differences in energy mix (fossil vs. renewables).

Applying an economics model to Construction CO_2, researchers find that **23% of CO_2 emissions from global economic activities can be attributed to the construction sector** [Huang2018].

23% of CO_2 is Construction CO_2. That's a lot. And this only covers emissions arising from the construction process itself, the so-called "embodied carbon", not emissions arising from the operation of the asset being built, such as heating, cooling, etc. of residential buildings.

Although the economics model applied to derive this number could easily be brought to include (most) other greenhouse gasses along with CO_2 [WIOD2012], the researchers for some reason chose not to do so. As far as your author is aware, a comprehensive analysis of *all* greenhouse gas emissions from the global construction sector has not been published. However, this is likely not a big problem, since most emissions from the construction sector are CO_2. Other greenhouse gasses primarily arise from agriculture, waste, and oil/gas extraction, refining, and processing, not construction [WRI2009]. From here on, let's focus exclusively on CO_2 emissions and forget about other greenhouse gasses for a while.

More problematic, perhaps, is the fact that the model compares CO_2 emissions from construction activities only with CO_2 emissions from other *economic activities*, apparently disregarding substantial (around 23%) CO_2 emissions from non-economic activities [PBL2018]. Would it be more reasonable to say that 18% of *total* global CO_2 emissions can be attributed to the construction sector?

Regardless of baseline (total CO_2 emissions vs. economic CO_2 emissions), the number is high enough to warrant our attention. So, let's dig a little deeper.

While 6% of CO_2 emissions in the construction sector are "direct emissions" stemming from on-site operation of construction machines and equipment, most emissions (94%) are "indirect emissions" stemming from off-site production of buildings materials [Huang2018]. The production of cement and steel is particularly heavy on the CO_2 accounts.

Cement production alone accounts for roughly 8% of total global CO_2 emissions [PBL2016]. Not 8% of CO_2 emissions from economic activity. 8% of *total* CO_2 emissions. Half of these emissions are generated by carbonate oxidation in the cement clinker production process, half are generated by fuel combustion during this process.

Steel production accounts for around 6% of total global CO_2 emissions [WSF2019]. Of course, not all steel is used in the construction sector, only around 30-35% [VIA, EUROFER2018], so approximately 2% of total global CO_2 emissions stem from the production of steel used in the construction sector.

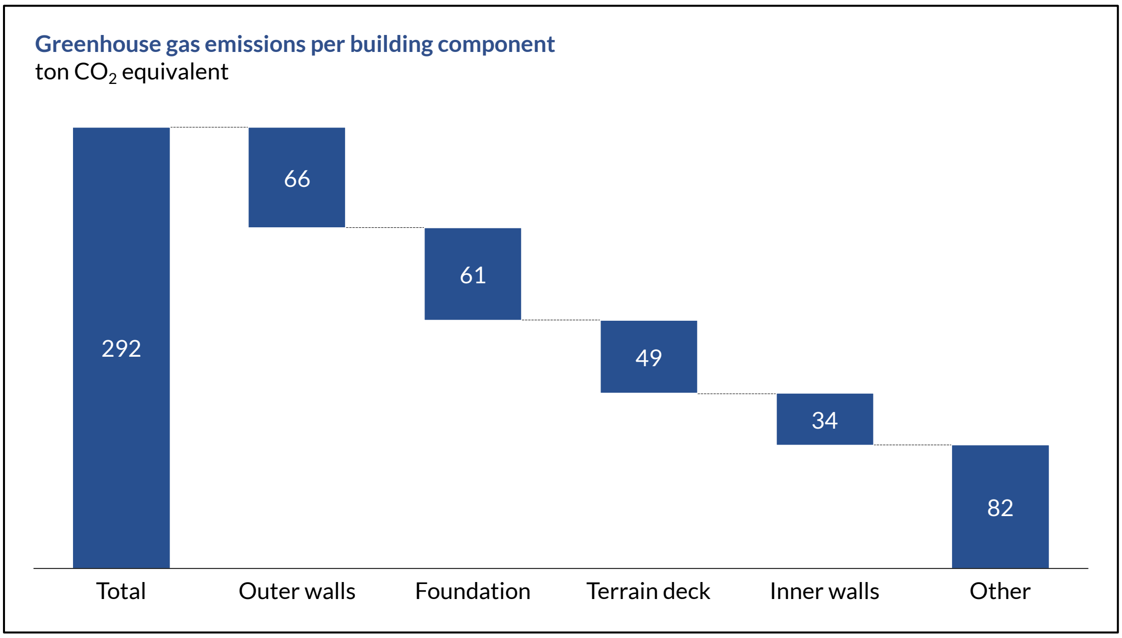
Brick and tile production also contributes significantly to the CO_2 emissions of the sector, as does the production of glass and thermal insulation materials.

Instead of going further down the (top-down) road of the global construction sector, let's look at a (bottom-up) example. And through this example, let's consider ways to reduce CO_2 emissions from the construction sector.

How can we reduce Construction CO_2?

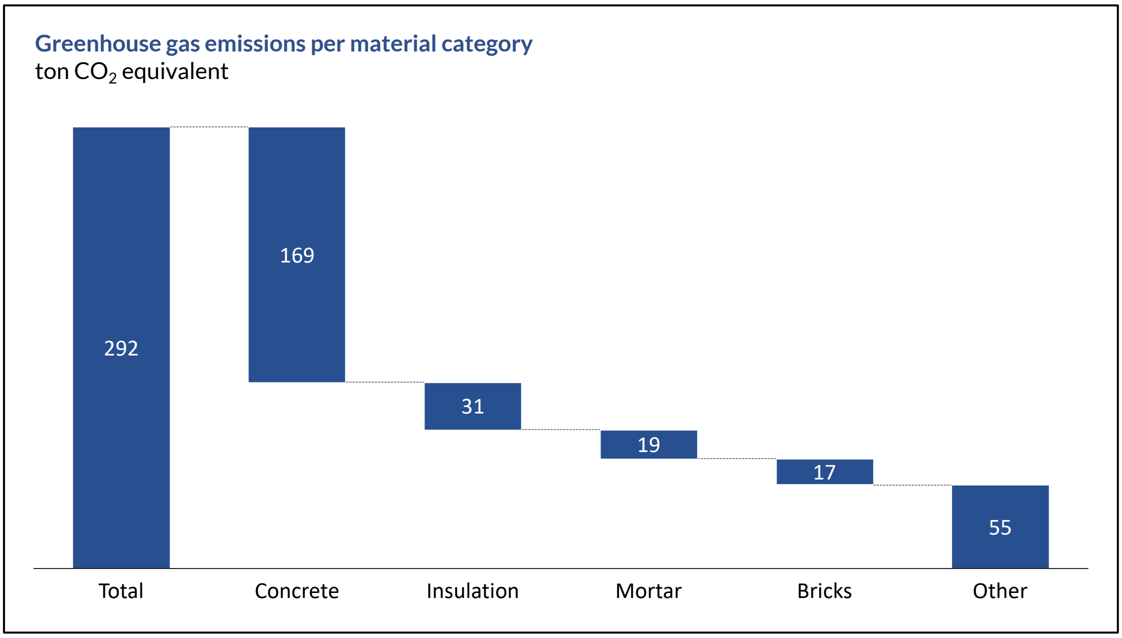
Let's look at a typical home. Let's look at 12 of them, actually. In the western part of Denmark, the local real estate developer partnered with the leading sustainability-focused architecture firm on a residential project with the objective to deliver six semi-detached houses and provide 12 units / 1,200 m^2 affordable housing for elderly citizens *and* a small outdoor common area to bind the neighborhood together.

If you want to reduce the carbon footprint of such a construction project, where do you begin? Well, if you wanted to reduce the *cost* of the project, surely you would look at the business case, identify the biggest cost buckets, and find ways to reduce those one by one. CO_2 emissions are no different.



spot solutions

Using the ABATE® tool [ABATE] to estimate CO_2 emissions per building component and material category, we found that the supply of raw materials, transport of these to manufacturing sites, manufacturing of building materials, and the construction process itself will cause greenhouse gas emissions on the order of 292 ton CO_2 equivalent.[1]



Let's stop and reflect for a moment. How much is 292 ton of CO_2 equivalent?

A lot of people are concerned about greenhouse gas emissions from cattle, since cows… Well, cows fart a lot. So, let's compare with emissions from steaks to understand the order of magnitude with which we are dealing. Beef generates around 27 kg CO_2 equivalent per kg of consumed meat [EWG], i.e. around 6.75 kg CO_2 equivalent per 250 g steak. Through simple arithmetic, we find that the 292 ton of CO_2 equivalent emitted corresponds to the emissions from 43,259 steaks. If you eat steak once per week today, and replace these steaks with chicken, which generates 7 kg CO_2 equivalent per kg of consumed meat [EWG], you would – in other words – need to *not eat steak* for 1,123 years to avoid emissions equivalent in magnitude to the emissions from this project. Construction is dirty. Steaks – in comparison – don't matter.

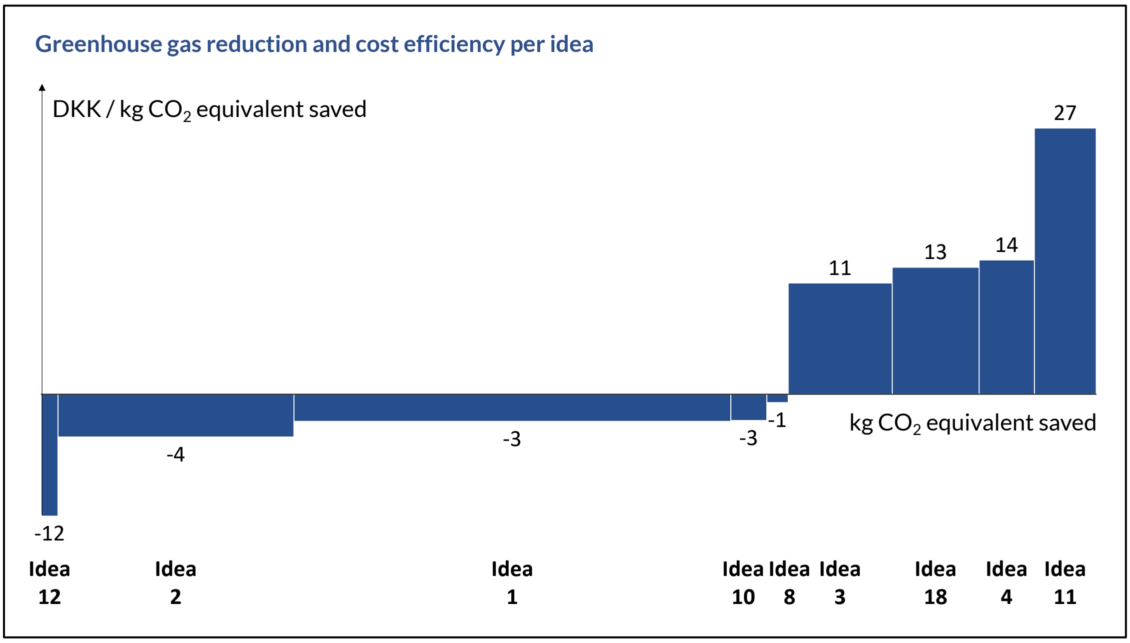
As the two charts above clearly show, most emissions (72%) are related to the four building components outer walls, foundation, terrain deck, and inner walls, and more than half of emissions (58%) are related to the use of building materials made of concrete.

[1] The internationally recognized EN 15804 standard defines 17 stages in the life cycle of buildings, from raw material supply over manufacturing and construction to building operations, decommissioning, and recycling. While all 17 phases should, in principle, be analyzed in a complete life cycle assessment (LCA), such an exercise is, in practice, too cumbersome and time-consuming for the typical building design process. Focus of the analyses behind this white paper was exclusively on phases A1-A5, i.e. raw material supply, transport to manufacturing site, manufacturing, transport to construction site, and construction. The unit of measure "ton CO_2 equivalent", for the avoidance of doubt, corresponds to 1,000 kg CO_2 equivalent. ("ton" refers to the "metric ton", not the US "short ton" or the UK "long ton")

In order to address these dominating "CO_2 buckets", to use language analogous to financial analyses, where dominating "cost buckets" are typically in focus, we generated and analyzed 23 ideas that were believed to reduce CO_2 emissions. The ideas were focused on finding alternative structures and materials for the four building components mentioned above, and special focus was on replacing materials made of concrete with suitable alternatives.

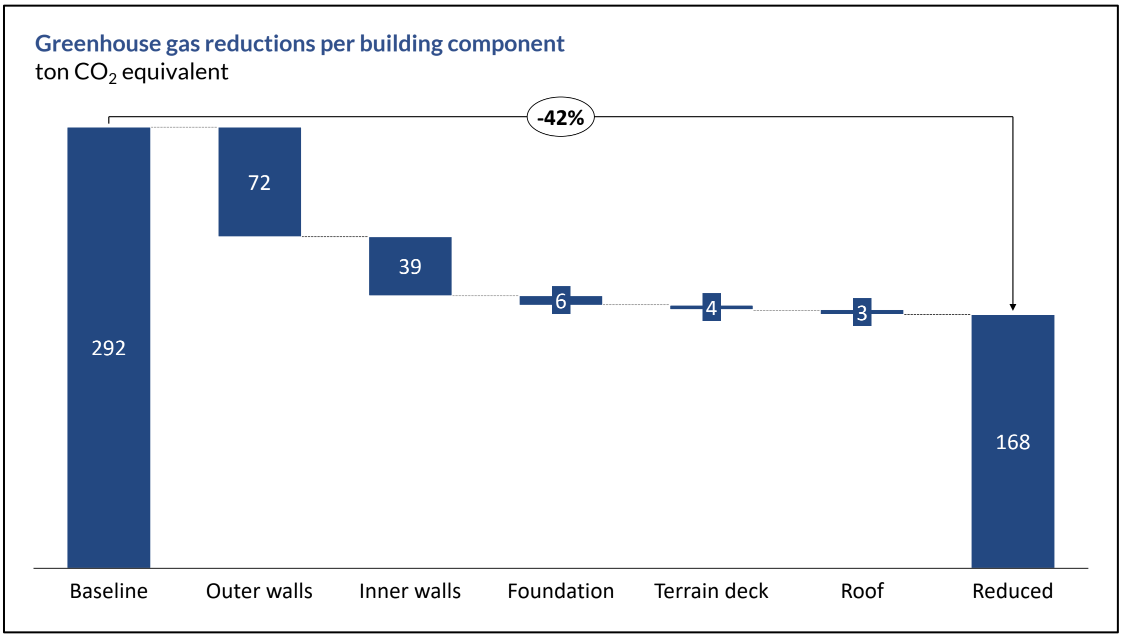
Examples of ideas: In the outer- and inner walls, replace building elements made from concrete with wood-based structures with similar qualities and durability. In the foundation and terrain deck, use recycled concrete. In the outer walls, use recycled bricks. On floors, replace oak with bamboo. For the outdoor common area, replace concrete pavement with wood.

Most of the ideas analyzed turned out to increase emissions, decrease emissions only marginally, or introduce unacceptably poor architectural aesthetics, but nine ideas proved to be very interesting. In the chart below, the CO_2 emission reduction for each of these nine ideas, measured in kg CO_2 equivalent saved, is represented by the width of the corresponding box, while the financial efficiency of this reduction, measured in DKK / kg CO_2 equivalent saved, is represented by the height of the box. The area of the box then represents the financial cost in absolute terms (measured in DKK).



The five ideas below the line were selected for implementation, while the four ideas above the line were rejected. Can you guess why? (if not, you'll find out in just a few moments)

The reduction in CO_2 emissions per building component is shown in the chart on the next page. Emissions for the outer and inner walls were reduced quite a lot, while emissions from the foundation, the terrain deck, and the roof also contributed a little. The total reduction in emissions was around 124 ton CO_2 equivalent, corresponding to 42% of the baseline emission.



Let's stop and reflect again. How much is 124 ton of CO_2 equivalent?

The Danish BR18 building regulations code [BR18] stipulates that the 12 homes built must consume a maximum energy of 37,000 kWh/year[2]. District heating consumes around 94 gram CO_2 equivalent per kWh energy consumed [ENS], which means that the maximum allowed emission is 3,478 kg CO_2 equivalent per year. In other words: The 124 ton of CO_2 equivalent avoided by implementing the five ideas corresponds to a minimum of 35 years of energy consumption for all 12 homes. Construction is dirty. Reducing Construction CO_2 makes a big difference.

That sounds expensive!

But what about costs? Will they increase? Not necessarily.

The five ideas implemented were all, as you may recall, found *below* the line of the chart on page 6, which means that the estimated cost of implementing each of them is negative. The ideas make the project cheaper, not more expensive.

In general, you should not expect to save money by reducing Construction CO_2, but if you go about it in a clever way, it may not cost much either.

That is it. That is the end of it. Quite straight forward, don't you think? Construction is big and ubiquitous, and it is a major source of CO_2 emissions. The sector needs to step up and improve. And it *can* improve, if we keep a calm head and go about CO_2 reductions the way we go about all other business improvement activities: You identify key "buckets" of emissions,

[2] The BR18 building regulations code covers energy for heating, hot water, ventilation, and cooling. For the analyzed project, the two former are delivered via district heating, while the two latter are assumed relatively, small since the 12 homes are built without air condition system.

develop ideas for reductions, estimate CO_2 and cost impact of each idea, and implement ideas that are good for the environment and come with an acceptable price tag. Simple, right?

Good luck in your Construction CO_2 reduction endeavors.

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