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Potential-analysis of grey energy limits for residential buildings in Germany

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ABSTRACT

European building regulations currently focus on the reduction of carbon emissions by reducing the primary energy demand for building operation. The embodied energy in construction materials is not limited by building regulations. In this study the potential for carbon savings by optimizing the grey energy, embodied in residential buildings in Germany, was analyzed. Therefore, representative sample buildings for the German building market were analyzed. Based on detailed statistical data about the German construction industry, results were transferred to the current building activity.

An enormous saving potential was determined. The global warming potential (GWP) of shell constructions could be reduced by up to 77% with existing technologies and without additional investment costs. Environmental cost savings of more than 1 billion €/yr could be realized for the German economy. With additional investments the saving potential could be increased to 95%. Though, such cost-intensive improvements would not be cost-efficient. Compared to further tightening of requirements on the energy efficiency the potential of reducing grey energy is much easier to tap. Thus, it is a reasonable next step to introduce requirements on the maximum GWP by grey energy in building regulations. Suggestions for such policy implementations were made.

1. Introduction

In the European Union buildings are responsible for about 40% of all carbon emissions [1]. Hence, since many years different measures were already implemented in European directives and national legislation to reduce carbon emissions in the building sector. Examples are ambitious measures to reduce carbon emissions by heating and cooling of buildings. Here significant improvements were realized by national regulations and for after 2020 it was even decided to introduce a so called “nearly zero-energy standard” for all new buildings in Europe [1]. This standard will require a high level of energy efficiency for thermal insulation and HVAC systems, while the residual energy demand will mainly have to be provided by renewable energy. The exact standard has to be defined by each member state and has to meet a cost-optimal level as described in [2]. All countries are obligated to report regularly to the EU and declare their actual level of building regulations and cost-optimality to ensure the progress towards the goal for after 2020.

Another measure for reducing carbon emissions is the obligatory utilization of renewable energy for building operation. This measure is less common in Europe, but for example in Germany it is already implemented in the building regulations [3,4].

An EU-wide measure for the reduction of carbon emissions that partially also affects the construction industry and thereby the whole building sector, is the emission trading system EU ETS (European Union Emission Trading System), introduced in 2005. A detailed overview about research for this trading system is given in [5]. In this system companies have to buy “emission rights” for their carbon emissions. Though, dependent on the branch they get a certain number of emission rights for free. All emission rates can be traded on the market. This emission trading system shall ensure that carbon emissions are saved, where costs are low. In theory this leads to the most cost effective carbon savings for the economy. However, the fact that certain numbers of certificates are free and the prices of the certificates are low, counteracts that theory. Moreover, the prices of emission rights do not comply with the expected long term costs caused by emissions. Prices in the EU-ETS market are extremely volatile as described in [6]. While the environmental costs were e.g. estimated with 80 €/ton CO_2 by the German Federal Environment Agency [7], the prices for emission rights ranged between approximately 30 €/ton CO_2 in 2008 and 5 €/ton CO_2 in 2013 [8]. In addition the emission rights became more and more to objects of speculation at the stock exchange, as described in [9]. This shows, that there is no direct relation between prices and environmental costs. Hence, this measure does not seem to be effective to

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limit the carbon emissions in the construction industry sufficiently. Therefore, several changes of this system were discussed already, as described in [10]. Or new systems for the construction industry are suggested as in [11].

However, measures covering all carbon emissions in the building process, would be required. The current building regulations such as in Germany [12], France [13] or UK [14] do not consider carbon emissions by embodied energy in construction materials at all. All building regulations just aim for reducing the energy for building operation (heating, cooling, hot water and partially electricity), but not for the production or disposal of construction materials.

In general the tightening of requirements for energy efficiency in building operation are to appreciate. Though, the marginal costs for energy efficiency measures do not increase linearly but exponentially, because it gets technically more and more elaborate to increase energy savings. Moreover, additional insulation also raises the embodied energy in buildings.

Today no regulations for the limitation of the grey energy, the carbon emissions during the construction process or the global warming potential (GWP) of buildings exist in Europe. However, due to increasing marginal costs for energy saving measures, it seems to be more cost-effective to tap also the potential of limiting the grey energy in buildings. Optional possibilities for such limitations already exist in sustainability certificates such as BREEAM, DGNB or LEED. Although, binding requirements are still missing. In addition sustainability certificates are usually just applied for commercial buildings. But the residential building sector, with a large share of 40% in Germany [15], is not affected at all by such certifications. Due to the missing assessment of the grey energy, most builders and architects do not even know how to reduce carbon emissions by grey energy and how big the potential is.

In research already many studies about the carbon emissions of grey energy in single buildings exist. In [16] it was analyzed that the share of grey energy in buildings will be increasing in future buildings. In [17] the energy demand of 60 buildings was analyzed for the whole life-cycle. Here is discovered that 9–46% of all energy is accounted for grey energy. This study covered low-energy buildings erected before 2007. As todayís and future energy standards are even more energy efficient, this share will even increase. The analysis shows on the one hand, that grey energy already accounts for a significant share in the life-cycle of buildings. On the other hand it shows the broad range between different buildings and highlights the existing saving potential by reduced grey energy.

The additional costs for the selection of construction materials with low global warming impact are expected to be low; especially compared to costs for measures to increase the energy efficiency in building operation. In international studies about the extra costs for so called "green buildings" it was shown that the highest costs in these buildings are caused by better energy efficiency and supply by renewable energy, but not by materials with a low GWP [18,19]. This confirms the assumption, that reducing the GWP by materials can be a very economic measure. In research, already significant progress for the reduction of carbon emissions by construction material exists. In [20] the carbon reduction potential for the cement industry were analyzed, in [21] improvement methods for the carbon footprint by optimization of structural systems were developed and in [22] reflective foils were suggested to reduce the carbon footprint by insulation material. Unfortunately most of such developments are not yet used in practice, because carbon savings are not sufficiently rewarded or respectively limited. However, due to the low expected costs of carbon savings in material production, changes in legislative regulations regarding grey energy in buildings seem to be very promising.

The saving potential of carbon emissions for the economy could be enormous and should no longer be neglected by policy-makers. To estimate this potential at national level the here presented study was undertaken. It was focused on the residential building sector in Germany. Because residential building constructions are much more homogeneous than commercial constructions, a potential analysis is a reasonable first step. In addition the residential building sector in Germany was already very progressive in the voluntary implementation of energy efficiency measures in the past. Compared to the commercial and industrial building sector, the residential sector is already far ahead concerning energy efficiency [23,24]. Hence, private building owners in Germany also seem to be a willing target group for further carbon reductions.

2. Theory/calculation

Fig. 1 gives an overview of the methodology of this research project. First, the global warming potential (GWP) of typical constructions was analyzed, based on environmental product declarations for different building materials (step 1, 2 in Fig. 1). This assessment of the GWP was based on DIN EN ISO 14025 [25] (year 2010). In 2014 this standard was actually replaced by DIN EN 15804 [26], but for most materials an assessment according to this newer standard is still not available.

In a next step substitutable constructions were defined (step 3 in Fig. 1). To ensure the substitutability of these constructions, they had to have the same optical appearance and technical quality as the compared constructions. For internal walls this means for example that they had to have the same sound reduction index and a comparable load bearing capacity. For external walls substitutable constructions also had to meet the same thermal quality (same thermal transmission coefficient) and of course the same load bearing capacity. All chosen constructions meet typical structural requirements. Thus, only approved typical German constructions were chosen to ensure that no further development is required and that all changes can be achieved with existing building technologies. The aim is to determine, which reduction of the GWP for single building components is possible by changing their materials without an impact on the quality.

In addition the costs of all constructions were estimated based on the electronic cost database "SirAdos" [27] (step 3a in Fig. 1). This cost calculation software provides average costs for German building constructions for the year 2015. This cost analysis should show, if additional costs occur for using materials with a reduced GWP.

For a transfer of the data to whole buildings it was required to define sample buildings, which are typical for German residential buildings (step 4a in Fig. 1). Here already defined sample buildings of a building database in [28,29] were used. In this database representative German residential buildings were defined, initially to estimate energy saving potentials by operational energy efficiency measures. These buildings were also used for official analyses for the German federal government to evaluate the last recast of the German building regulations [12].

Hence, choosing these sample buildings also allows to compare carbon savings by energy efficiency measures with carbon savings by reducing grey energy in the same buildings. A quantity survey (step 4b in Fig. 1) allowed to determine the GWP of the building shell of all sample buildings for different variations on the building constructions (step 4 in Fig. 1).

Based on statistical data about the German construction activity [30,15] (step 5a in Fig. 1) it was possible to make rough estimations of existing saving potentials for the whole German economy by a change to more sustainable construction materials (only shell constructions of residential buildings), (step 5 in Fig. 1). Based on the undertaken cost comparisons, this also allowed an estimation of the monetary saving potential of consequential environmental costs.

As a last step reasonable restrictions e.g. by building regulations were discussed (step 6 in Fig. 1). In addition the carbon emissions