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# Mitigating environmental impacts through the energetic use of wood: Regional displacement factors generated by means of substituting non-wood heating systems

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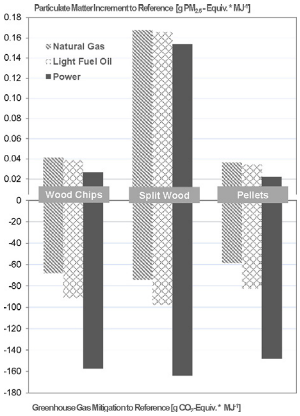
## HIGHLIGHTS

- Stratified displacement factors through wood heating in Bavaria were developed.
- A method for creating displacement factors in other regions is suggested.
- Wood heating entails substantial GHG mitigation effects but increased PM emissions.
- Wood heat displaces −90.3 g $CO_2$-eq.∗$MJ^{-1}$ compared to the fossil heating mix.
- The reference system has the biggest impact on the magnitude of GHG mitigation.

## GRAPHICAL ABSTRACT



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## ABSTRACT

Wood biomass, especially when applied for heating, plays an important role for mitigating environmental impacts such as climate change and the transition towards higher shares of renewable energy in today's energy mix. However, the magnitude of mitigation benefits and burdens associated with wood use can vary greatly depending on regional parameters such as the displaced fossil reference or heating mix. Therefore, regionalized displacement factors, considering region-specific production conditions and substituted products are required when assessing the precise contribution of wood biomass towards the mitigation of environmental impacts. We carried out Life Cycle Assessments of wood heating systems for typical Bavarian conditions and substitute energy carriers with a focus on climate change and particulate matter emissions. In order to showcase regional effects, we created weighted displacement factors for the region of Bavaria, based on installed capacities of individual wood heating systems and the harvested tree species distribution. The study reveals that GHG displacements between −57 g $CO_2$-eq.∗$MJ^{-1}$ of useful energy through the substitution of natural gas with a 15 kW spruce pellets heating system and −165 g $CO_2$-eq.∗$MJ^{-1}$ through the substitution of power utilized for heating with a modern 6 kW beech split log heating system can be achieved. It was shown that the GHG mitigation potentials of wood utilization are overestimated through the common use of light fuel oil as the only reference system. We further propose a methodology for the calculation of displacement factors which is adaptable to

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other regions worldwide. Based on our approach it is possible to generate displacement factors for wood heating systems which enable accurate decision-making for project planning in households, heating plants, communities and also for entire regions.

## 1. Introduction

Environmental effects of wood biomass through a material or energetic application can entail benefits associated with the displacement of other, often times more harmful, building materials or energy carriers (Sathre and O'Connor, 2010). Existing European and German policies consider the use of biomass to entail GHG reductions and subsequently aim to promote bioenergy (EC, 2009; Bundesregierung, 2011). Not all uses however, are equally suitable for a renewable, but not infinite resource such as wood which offers a wide array of potential applications, not only as an energy carrier, but also as a building material or as raw material for the chemical industry (BMU, 2014).

One application which has historically been well suited and important for wood, both in developed and developing countries, is the provision of heat which is even more evident in the structure of today's heating mixes, where e.g. in Bavaria approximately 80% of renewable heat is provided by solid biomass (solid biomass is the term used in the official statistics published by the Bavarian State Institute for Statistics and Data Processing for a group of energy carriers which consists to more than 95% of wood) (Wolf et al., 2016). Especially, if an increase in the supply of sustainably produced wood is not to be expected in the future, the most efficient technology for the consumption of wood should be prioritized. Due to high efficiencies when compared to other applications, such as the generation of power or transportation fuels, the conversion of wood to heat can fulfill this condition (Cherubini and Strømman, 2011). Of course, an efficient resource use can also be obtained by increasing the lifetime of products and through the cascading of its resources, followed by a final thermal use of the wood (Höglmeier et al., 2015).

Hence, the total benefit or burden of the wood utilization system is quantified as the sum of environmental effects, typically identified through life cycle assessments (LCA), associated with the production of the wood product in comparison to the environmental effects associated with the production of one or more reference products which are displaced by the wood product.

For the wood in building products, a variety of studies assess the displacement of conventional building materials with wood and provide conferrable displacement factors which can be utilized for any sufficiently equal building product (Taverna et al., 2007; Sathre and O'Connor, 2010; Suter et al., 2016). For energy systems the regional displacement is determined by a national mix or supplier mix of energy carriers, and therefore no general and conferrable displacement factors can be disclosed. Identifying the mix of energy carriers for the provision of power is rather trivial, whereas this does not hold true for the provision of heat. Its decentralized structure and lacking obligations to report fuel consumptions and emissions pose a challenge when determining the heating mix and subsequent displacements. For this reason, typically a mix of light fuel oil (LFO) and natural gas, or only one of them is used when assessing the GHG mitigation potentials of a heating system (Jäppinen et al., 2014; Felder and Dones, 2007; Ghafghazi et al., 2011; Esteban et al., 2014; Katers et al., 2012; Knauf et al., 2015). This can, due to the aforementioned importance of the reference system, lead to skewed results and flawed interpretations and the actual GHG mitigation through using wood for heating is not depicted. This is why the utilization of stratified emission factors is practiced by the annual national Greenhouse Gas inventory report under the UNFCCC, where actual GHG emissions of the energy mix, also for heat, are reported (Umweltbundesamt, 2014). Since the choice of reference system consequently is of great impact towards the interpretation of the LCA, it should be carefully chosen in order to reflect the actual displacement occurring. Finally, actual GHG mitigation effects are a matter of scaling and differ for systems like a household, a community, a region or a country. It is therefore the aim of this study to provide GHG mitigation factors for the displacement of energy carriers through various wood heating systems in Bavaria, southern Germany. In our research we addressed the following research questions:

1. What methodical steps are required in order to depict the environmental effects of the displacement of various energy carriers with wood used for heating on a household and on a regional level and how can these methods be transferred to other countries or regions?
2. On the example of Bavaria, what is the magnitude of GHG mitigation of the most frequent wood heating systems when displacing individual non-wood energy carriers or a weighted heating mix currently used for the provision of heat in the study region of Bavaria?
3. What are environmental tradeoffs, e.g. in the form of emissions of particulate matter, associated with the GHG mitigation of wood heating systems?

## 2. Material and methods

Determining the magnitude of a displacement, i.e. the amount of environmental effects caused by a system in comparison to a reference system requires the examination of both systems' life cycles. In the case of this study, the displacement effect (further described as "displacement factor") is the difference between the non-wood and the wood system, where a system can be a single heating appliance, a heating plant or an entire region.

$$\text{Displacement effect} = \text{Environmental Burden}_{\text{wood}} - \text{Environmental Burden}_{\text{non wood}}$$

For this study, environmental effects, with a focus on GHG emissions, of wood heating systems and their reference systems, both fossil and renewable, were analyzed through LCA in accordance to DIN EN ISO 14044 (DIN, 2006). The selection of assessed wood heating systems in the case study area is based on Joa et al. (2015), which, by means of expert interviews and literature, represents the installed capacities and location of wood heating systems in Bavaria in the year 2012, while the modeling of the wood heating systems (i.e. the employed emission factors) follows the assumptions of Wolf et al. (2016). A system description and the applied modeling parameters for the wood heating systems can be found in Fig. 1.

The life cycle of each heating system starts with the raw material acquisition phase which is the provision of wood [A]. Due to similarities in wood properties of native softwoods, heating systems utilizing softwood were modeled as if spruce was employed. The same applies for native hardwoods, which were modeled as beech. In the subsequent transformation phase [B], three assortments of wood energy carriers, split wood, wood chips and wood pellets are produced, transported [T] and converted into final energy [C] through a variety of energy carrier specific heating systems (Fig. 1). All systems were modeled from cradle to grave with the omission of the waste treatment phase [E], which is of very minor impact for most heating systems and is cut off following the <1%/95% cut-off rule in the global warming impact category (Wolf et al., 2016).

Impact assessment, with a focus on GHG emissions, was conducted in accordance to the ILCD Handbook (European Commission, 2010).