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Carbon accounting of material substitution with biomass: Case studies for Austria investigated with IPCC default and alternative approaches

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ABSTRACT

There is evidence that the replacement of carbon-intensive products with bio-based substitutes ('material substitution with biomass') can be highly efficient in reducing greenhouse gas (GHG) emissions. Based on two case studies (CS1/2) for Austria, potential benefits of material substitution in comparison to fuel substitution are analysed. GHG savings are calculated according to default IPCC approaches (Tier 2 method assuming first-order decay) and with more realistic approaches based on distribution functions. In CS1, high savings are achieved by using wood residues for the production of insulating boards instead of energy. The superiority of material substitution is due to the establishment of a long-term carbon storage, the high emission factor of wood in comparison to natural gas and higher efficiencies of gas-fired facilities.

The biomass feedstock in CS2 is lignocellulosic ethanol being used for bio-ethylene production (material substitution) or replacing gasoline (fuel substitution). GHG savings are mainly due to lower production emissions of bio-ethylene in comparison to conventional ethylene and significantly lower than in CS1 (per unit of biomass consumed). While CS1 is highly robust to parameter variation, the long-term projections in CS2 are quite speculative.

To create adequate incentives for including material substitution in national climate strategies, shortcomings of current default accounting methods must be addressed. Under current methods the GHG savings in both case studies would not (fully) materialize in the national GHG inventory. The main reason is that accounting of wood products is confined to the proportion derived from domestic harvest, whereas imported biomass used for energy is treated as carbon-neutral. Further inadequacies of IPCC default accounting methods include the assumption of exponential decay and the disregard of advanced bio-based products.

1. Introduction

The substitution of fossil fuels with biomass is a core element of the EU's climate and energy strategy (see European Commission, 2011; Beurskens and Hekkenberg, 2011; Kalt et al., 2012). Much less promoted is material substitution with biomass, despite evidence that the replacement of energy-intensive materials with bio-based counterparts can be highly efficient in reducing greenhouse gas (GHG) emissions (Sathre and O'Connor, 2010; Gustavsson et al., 2007; Burschel et al., 1993; Perez-Garcia et al., 2007; Kalt et al., 2015; Sikkema and Nabuurs, 1995; Sathre and Gustavsson, 2006). In optimal applications of long-lived bio-based products the benefits of material substitution are threefold: (1) Energy consumption and GHG emissions from production processes can be reduced, (2) biogenic carbon is stored over a considerable period of time instead of being released into the atmosphere and (3) bio-based products can be used as renewable fuel or secondary raw material at the end of their lifespan ('cascading biomass use').

The 1996 IPCC Guidelines assumed that all carbon removed from forests is oxidized in the year of harvest (Grêt-Regamey et al., 2008). Hence, a main advantage of material substitution over fuel substitution was disregarded in GHG accounting, creating a

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considerable 'incentive gap' (cf. Ellison et al., 2011), as this methodology favoured bioenergy over material use (Ellison et al., 2014).

Recognizing that the dynamics of artificial carbon pools in the form of long-lived wood products are actually quite relevant, accounting of 'harvested wood products' (HWP) was made obligatory for the second commitment period of the Kyoto protocol from 2013 to 2020 (cf. Frieden et al., 2012). Several accounting methods have been under discussion, and the implications, incentives and shortcomings of different approaches have been compared and discussed thoroughly (e.g. Lim et al., 1999; Grêt-Regamey et al., 2008; Kohlmaier et al., 2007). The current IPCC Guidelines (IPCC, 2014) define some general rules and good practice guidance for HWP accounting, but also leave methodological options open; most notably the treatment of international trade with HWP and the selection of decay functions, which determine the temporal distribution of outflows from the carbon pool (based on typical product lifespans).

The most common approach, which is also applied in Austria's GHG inventory report (Umweltbundesamt, 2015), is the default 'Tier 2 method' with system boundaries according to the 'production approach' (PA) (cf. Pilli et al., 2015; Brunet-Navarro et al., 2016; Butler et al., 2014; Sikkema et al., 2013; Yang and Zhang, 2016). Under Tier 2 it is assumed that HWP carbon stocks decline according to a first-order (exponential) decay function. All HWP produced from domestic harvest are considered as inflow to the pool under the PA, regardless of whether they are exported or consumed domestically (cf. Pingoud et al., 2003; Pingoud et al., 2006). It has further been argued that exponential decay is actually unrealistic for many (especially long-lived) wood products, because it assumes high outflows from the HWP pool in the first years (cf. Cherubini et al., 2012; Marland et al., 2009). Hence, it is questionable whether results of the default Tier 2 method appropriately reflect carbon stock changes (cf. Supplementary material for a more detailed description of the default Tier 2 approach).

So far there is hardly any literature focusing on the GHG mitigation resulting from material substitution under different accounting approaches; only one case study for Canada by Sikkema et al. (2013) is known, where only first-order decay is considered. Considering the EU's long-term commitment to establish a bioeconomy until 2050 (European Commission, 2012), material substitution will likely become increasingly important in Europe; and so will carbon accounting of bio-based products. The benefits of material substitution compared to fuel substitution are of special interest, as enhanced cascading biomass use is considered essential for a sustainable and efficient biomass sector (Keegan et al., 2013; Van Lancker et al., 2016). Therefore, appropriate methods for analysing specific utilization paths need to be developed.

2. Research question

This work seeks to quantify the climate benefits of material substitution as compared to fuel substitution under different accounting approaches. A specific methodology for comparing GHG mitigation from material substitution and fuel substitution is presented. A special focus is put on the implications of different decay functions used for modelling outflows from HPW stocks.

Two case studies (CS) are investigated: Wood insulating boards produced from wood residues (CS1) and bio-ethylene produced from lignocellulosic ethanol (CS2). A core objective is to identify implications of different accounting methods and general shortcomings of the default approach.

Due to the long-term nature of the assumed market developments and according carbon pool changes, the considered timeframe is 2015–2075. The robustness of results against uncertain parameters is investigated in sensitivity analyses. The case studies are based on conditions in Austria, but most findings – especially about methodological issues – are universally valid.

3. Methodology

3.1. Decay functions

Distribution functions with the highest probability near the typical product lifespan are considered more appropriate than exponential decay for modelling carbon stocks of long-lived

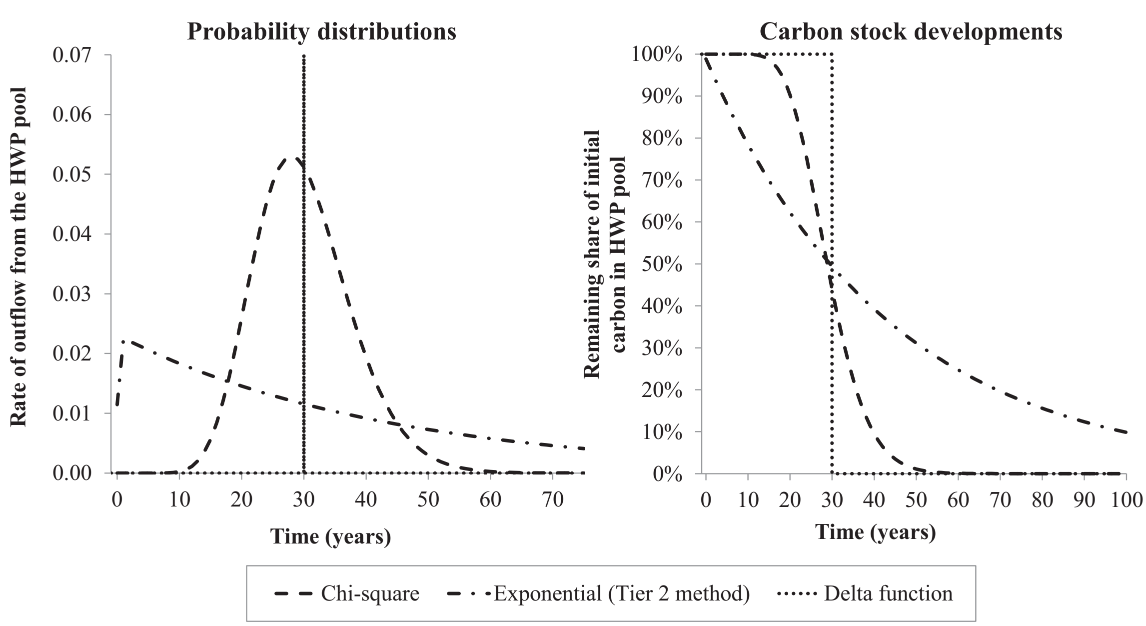

Fig. 1. Probability distributions used to model carbon stock changes of wood products (left) and according carbon stock developments assuming a single inflow at t = 0 (right). Source: Authors' illustrations based on Cherubini et al. (2012) and IPCC (2014)