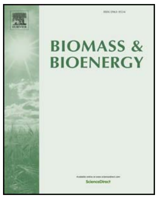
Biomass and Bioenergy 108 (2018) 167–177

Contents lists available at ScienceDirect

Biomass and Bioenergy

journal homepage: www.elsevier.com/locate/biombioe



Research paper

How harmful is burning logging residues? Adding economics to the emission factors for Nordic tree species

Aapo Rautiainen*, Jussi Lintunen, Jussi Uusivuori

Natural Resources Institute Finland (Luke), Helsinki, Finland

ARTICLE INFO

Keywords:
Emission factor
Logging residues
Bioenergy
Carbon
Time preference
Social cost of carbon
Picea abies
Pinus sylvestris
Betula pendula

ABSTRACT

Replacing fossil fuels by logging-residue-based bioenergy has been proposed as a way to mitigate climate change. If residues are combusted for energy, their carbon content is released immediately. Residues, that are not combusted, decompose and emit carbon gradually. The relative harmfulness of bioenergy emissions therefore depends on how strongly we prefer the slow release of carbon to an immediate one. Two factors affect this judgment: (1) our time preference and (2) our expectations regarding the relative harmfulness of future carbon emissions. Neither aspect is included in established biomass emission factors. The Effective Emission Factor (EEF), outlined in this study, includes both aspects in a transparent and tractable way. We demonstrate the concept by deriving the EEFs for the logging residues of three Nordic tree species: Norway spruce (Picea abies), Scots pine (Pinus sylvestris) and silver birch (Betula pendula). We also examine the sensitivity of the results to variation in time preference and damage expectations. The derived factors can be used to compare the harmfulness of carbon emissions from residue-based bioenergy and fossil fuel combustion and to organize bioenergy carbon taxation consistently with the taxation of fossil fuels.

1. Introduction

Logging residues from Nordic boreal forests are a renewable energy source. It has been argued that –although residue-based bioenergy is not emission free– it can help mitigate climate change, as total anthropogenic carbon emissions can be in the long run reduced by replacing fossil fuels by bioenergy [1–3]. The carbon intensity of fossil fuels is usually compared using emission factors, such as those recommended by the IPCC [4]. These factors measure immediate fuel combustion emissions. If the fuels are not combusted, no carbon is released. The same is not true for logging residues, which decompose and release carbon even if they are not utilized for energy. Constructing emission factors for residues therefore requires establishing the trade-off between current and future emissions, which is a question of economic cost-benefit analysis. This trade-off is not taken into account in pre-existing biomass emission metrics (e.g. Refs. [5,6]) apart from the Effective Emission Factor (EEF) [7].

The “harmfulness” of CO_2 emissions from residue or fossil fuel combustion can be measured in terms of social cost (i.e. the present monetary value of the social damage caused by the emissions). The EEF can be used to compare the harmfulness of fossil fuel and residue-based bioenergy emissions. As the concept is only briefly introduced in the original source [7], we discuss it here in detail. We explain its theoretical foundations and derive the EEFs for the three most common Nordic tree species. Similar factors – for any type of biomass – have not been published previously. Thus, this study serves as a proof of concept. The same idea is also applicable to residues of other tree species as well as agricultural residues. As an example of a practical application for the concept, we show how it can be used to organize the carbon taxation of logging residue-based bioenergy in a way that is consistent with fossil fuel taxation. Similar economic consistency is not attained if other pre-existing metrics are used for the same end.

1.1. Why is an economic approach needed?

Three aspects are critical in determining the trade-off between immediate emissions from residue combustion and gradual emissions from residue decomposition. The first is the emission profile (i.e. how much CO_2 is emitted, if the residues are burned, and what is the alternative time trajectory of the emissions, if the residues are left to decompose). The second is how the harmfulness of CO_2 emissions is expected to change over time (i.e. is emitting one tonne today more or less harmful than it is e.g. next year?). The third is the time preference (i.e. how strongly do we prioritize our current welfare compared to that of the future generations?). Based on these three factors, the harmfulness of emissions from residue combustion can be established and compared to

---

* Corresponding author.
E-mail addresses: aapo.rautiainen@luke.fi (A. Rautiainen), jussi.lintunen@luke.fi (J. Lintunen), jussi.uusivuori@luke.fi (J. Uusivuori).

https://doi.org/10.1016/j.biombioe.2017.11.010
Received 15 January 2016; Received in revised form 9 November 2017; Accepted 10 November 2017

fossil emissions.

A one tonne CO_2 pulse emitted today halves in the atmosphere in 45 years. A third of it remains there even after 260 years [8]. The fraction remaining in the atmosphere at any given point in time contributes to global warming, which is damaging to ecosystems and human well-being [9]. Economists measure these damages in monetary terms. The Social Cost of Carbon (SCC) is the present value of the future damages caused by the marginal tonne of CO_2, emitted at time t (see e.g. Ref. [10] or [11]). Thus, the SCC measures the harm caused by a CO_2 emission pulse (a mathematical definition for the SCC is provided in Supplement [S1]). The harm caused by burning residues is caused by advancing the timing of the emissions [7]: i.e. when the value of the damage is discounted, immediate damage is considered more harmful than gradual future damage of equal proportion.

Pre-existing biomass emission metrics are based on a different kind of thinking. The GWP_{bio} index [5] accounts for the climatic impacts as follows. Burning biomass releases carbon. The release is then compensated for by growing new biomass which gradually removes the carbon from the atmosphere (some carbon is also removed by the rest of the biosphere and the oceans). The climatic impact of a pulse emission is the time-integrated radiative forcing caused by the fraction remaining in the atmosphere until the pulse is fully compensated for. In Ref. [6] the concept is further refined to include a displacement factor [12] to account for the fossil emissions that are avoided by substituting bioenergy for fossil fuels.

Applying the GWP_{bio} index approach to the regulation of residue-based bioenergy is problematic for two reasons. First, it does not address the emissions that occur if the residues are left to decompose on site. Second, it rewards biomass user for future carbon removals which (usually) someone else will be responsible for. This has repercussions if carbon impacts throughout the economy are regulated based on a welfare-maximizing carbon pricing policy [7] or [13,14]. Under such a policy, all emissions and removals are equally priced according to the SCC [13]. Removals by growing biomass are subsidized [7,15], while emissions from combustion and decay are taxed [7]. These incentives encourage landowners and consumers to increase removals and reduce emissions by adjusting forest management and biomass use. However, if the reward for future removals is in advance given to someone else than the landowner, her incentives are distorted and the policy does not guide her behavior correctly. Thus, the landowner – rather than the consumer – should be rewarded for the removals. Similarly, for consistency, a displacement factor should not be used to reward the biomass user for avoided fossil emissions [7]. If fossil emissions are taxed, the reward for avoided fossil emissions –i.e. avoided taxes– is already given to the consumer who reduces fossil fuel consumption. Rewarding the biomass user for the same reductions amounts to double-counting.

The climatic impacts of Nordic residue-based bioenergy have been studied by Repo et al. [2,16,17], using life-cycle assessments (LCA) methods. Similar studies conducted elsewhere are reviewed in Ref. [18]. Our method, based on cost-benefit analysis, differs from this approach in two ways: (1) we account for the changing SCC over time, and (2) we include an explicit time preference rate.

The radiative forcing caused by incremental CO_2 emissions (slightly) decreases as the atmospheric carbon concentration increases [19]. Thus, a CO_2 tonne emitted in the future warms the atmosphere less than one emitted today. The impact of the changing atmospheric mixing ratios on radiative forcing is taken into account in appropriately conducted LCAs [20], such as [2]. However, measuring radiative forcing alone is not enough to capture the harmfulness of emissions. Radiative forcing causes warming which causes social damage. Thus, the harmfulness of an emission pulse depends on (i) the temporal radiative forcing profile of the pulse, and (ii) development of the social cost of (i.e. the value of the damage caused by) marginal radiative forcing over time [21]. The latter is expected to increase over time as climate change proceeds and the global economy grows [21–24]. This impact is not captured by purely physical metrics based on radiative forcing, such as Global Warming Potential (GWP) [25]. GWP is commonly applied in LCA for making comparisons between greenhouse gasses and over time [20]. The Absolute Global Warming Potential (AGWP) of a gas is the time-integrated radiative forcing caused by an emitted tonne over a given timespan (usually 100 years). The GWP of the gas is the ratio of its AGWP to that of CO_2. Thus, because AGWP and GWP are pure 'forcing metrics', they do not sufficiently measure the harmfulness of emissions [26,27]. Other alternative climate metrics are reviewed in Refs. [29,30].

The fact that radiative forcing can be measured more accurately than climate damage may explain why 'forcing metrics' are preferred to 'damage metrics' in LCA. Forcing estimates are somewhat uncertain [29], but damage estimates are even more so, as they contain the uncertainty of the forcing caused by the emissions as well as that of the damage caused by the forcing [21]. However, the results of LCA studies are used to inform policy about the relative harmfulness (or harmlessness) of using alternative feedstocks. If climate policy is e.g. based on the principle of welfare maximization (i.e. maximizing the difference between social benefits and costs), the monetary value of damage is a more relevant variable than forcing. By conducting our analysis using a damage metric we therefore aim at regulating the accurate policy target (damage) at a low precision, rather than an inaccurate target (forcing) at a higher precision.

Time preference is the second major difference between cost benefit analysis and LCA. In economics, the discount rate indicates time preference. A positive discount rate implies that the costs and benefits (of e.g. reducing emissions), incurred tomorrow, are given less weight than those incurred today (higher the rate, the smaller the weight). In LCA, on the contrary, there is (usually) no explicit time preference [20]. All emissions are weighted equally regardless of their timing, which is the same as applying a zero discount rate. However, there is a 'hidden time preference' that depends on the choice of time horizon of the emission metric (e.g. GWP_{100} gives equal weight to all radiative forcing incurred during the first hundred years, but zero weight to that incurred thereafter). Thus, applying a short (long) time horizon emphasizes immediate (gradual) climatic impacts. Also an explicit time preference can be included in LCA [28] but, so far, it has not become a common practice.

The question of time preference is central to establishing what weight we give to reducing net emissions today vs. reducing them in the future. There is no 'objectively correct' time preference. Likewise, noone can exactly foretell the future development of the SCC. However, despite these uncertainties, 'time preference' and 'damage expectations' are crucial variables that cannot be disregarded without losing policy-relevance [26]. We show how these variables can be taken into account in a transparent and tractable manner.

2. Materials and methods

2.1. Social cost of carbon as a measure of damage

The SCC at any given point in time depends on the expected future damages and the rate at which they are discounted. The appraisal of global damages that occur in the future is naturally subject to large uncertainties. Damage estimates vary considerably [24,31]. Likewise, economists' views regarding the rate at which environmental costs and benefits should be discounted vary (see e.g. Stern vs. Nordhaus [32,33]). Nevertheless, most economists tend to recommend the use of relatively low, positive discount rates [34].

SCC time paths are usually projected using integrated assessment models, e.g. Refs. [22,35,36]. One meta-analysis of these projections suggests that, on average, the SCC estimates rise at an annual rate of 2% [24]. The Interagency Working Group (IWG) in the United States (under the Obama administration) produced SCC guideline values [37] that can be applied in public policy related cost-benefit analyses (see Ref. [10] for discussion). The guideline values for 3% and 5% discount