Paying for What You Get: Accounting for the Nonrenewable Component in Wood to Energy

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Abstract

Growing international trade in wood pellets is one response to regional efforts to mitigate the global problem of climate change. With this growing use of wood energy, there is increased scrutiny of the associated environmental impacts and concern over possible unintended consequences (e.g., nonrenewable energy inputs) that may detract from the carbon savings provided by such renewable energy sources. The focus of this article is to present an accounting system for the embodied fossil fuels in wood energy systems. This system is based on life-cycle assessment methodology and could accommodate fairly the variability in fossil fuel inputs for various bioenergy systems. Such a system could be incorporated into biofuel subsidies or carbon taxation policies. We use three scenarios as examples to illustrate (1) that wood-to-energy systems entail the use of fossil fuels and that the amount of this ''embodied fossil carbon'' varies with the processing inputs and transportation required and (2) that carbon tax/biofuel subsidies can be adjusted to accommodate variations in embodied fossil carbon. The growth in life-cycle databases and the advent of environmental product declarations make embodied fossil fuel calculations such as those presented here an increasingly practical component of biofuels policy development.

Climate change is a global problem tied closely to energy production that is being addressed locally, e.g., by programs in Europe that encourage the use of wood pellets in place of fossil fuels. Specifically, the European Union (EU) adopted the Renewable Energy Policy in 2009, mandating that renewable energy sources constitute 20 percent of the final energy consumption for all EU countries by 2020 and 10 percent in the transportation sector (European Commission 2013). In response to these mandates, the EU member states adopted a wide range of policies to encourage increased use of renewable energy sources, including biomass such as wood pellets (see, e.g., Joudrey et al. 2012). These policies include mechanisms such as carbon credits or subsidies to reward reduced reliance on nonrenewable sources. Other policies discourage the use of fossil fuels through disincentives, such as carbon taxes. Belgium, as one example, has combined approaches by reducing the awards for electricity generation with renewable energy sources by a deduction for the amount of fossil fuel used to prepare and transport the biofuel (Van Stappen et al. 2003). Some of the policy instruments affecting the demand for wood pellets include direct subsidies and tax credits for biomass boilers or heaters, wood energy advisers to assist organizations and individuals adopt wood energy, and regulations mandating the use of certain percentages of renewable energy sources. As a consequence of these policy actions, EU demand for all forms of renewable energy is projected to increase in the coming decades, with some of this demand being met by wood pellets from the United States and Canada (Goetzl 2012) and other supplies covered mostly by Europe, including Russia (Goh et al. 2013, Proskurina et al. 2014). The IEA Bioenergy Task 40 predicts between 16 and 33 million tons of wood pellets being traded globally by 2020 (International Energy Agency 2012).

These policies currently do not address the issue of ''embodied fossil carbon'' in solid biofuels, where the potential climate benefit of biomass for fossil substitution is partially offset by the fossil fuel expended in generating and transporting the biomass fuel to the user. This use of fossil

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fuels reduces the net benefit to the global climate of increasing renewable energy use. In this context, we define embodied fossil carbon as carbon dioxide emissions to the atmosphere resulting from the use of fossil fuels associated with the use of solid biofuels.

In this analysis, we make a distinction between ''fossil carbon'' and ''bio-carbon.'' Burning fossil fuels releases carbon dioxide (fossil carbon) to the atmosphere, and this is the main driver of climate change (Intergovernmental Panel on Climate Change 1996). We assume that the release of carbon dioxide from burning biomass (bio-carbon) has no net effect on climate change because the carbon dioxide released during combustion was recently removed from the atmosphere (sequestered) by the growing plant (photosynthesis). Implicit in this assumption is the assumption of the sustainable production of biomass fuel on a landscape level. However, the provision of biomass fuels almost always requires some fossil fuel energy input (''embodied fossil energy''), such as gasoline from petroleum to power a chainsaw to cut a tree that will be used for firewood. The fossil carbon emissions from using this gasoline would be an example of ''embodied fossil carbon'' associated with the use of this firewood.

Life-cycle assessment (LCA) is a method for evaluating the environmental impacts of products. The basis of LCA is the life-cycle inventory (LCI), which is a holistic account of the material and energy inputs and associated emissions required for a product's manufacture, use, and disposal. LCA methodology is standardized (International Organization for Standardization [ISO] 2006b, 2006c), and large LCI databases have been developed (Weidema et al. 2009, National Renewable Energy Laboratory [NREL] 2012). LCI data for a product or component process are often entered into life-cycle impact assessment (LCIA) models (e.g., TRACI [Bare 2011]) to estimate the total impact of the many inputs and emissions on a particular environmental parameter of interest. For example, fossil fuels are used directly (diesel for truck transportation) and indirectly (coal for electricity used to power a pellet mill) at various stages in the production of wood pellets. LCI data, and an LCIA model, can be used to evaluate the total greenhouse gas emissions associated with wood pellet production and transportation. LCA can be used to identify the components of the life cycle that produce the greatest environmental impact; it can also be used to compare products. Both of these uses can be applied to evaluations of biofuels: LCA can reveal the relative importance of the various production steps and can be used to compare potential fuel sources. Thus, LCA can assess the potential for carbon benefits when substituting wood pellets for fossil fuel alternatives as part of a climate mitigation strategy.

The sustainability of solid biofuels in general and American pellet exports to Europe in particular has been debated (Walker et al. 2010, Woodworth 2012, Cabin 2013, Langer 2014). The issue of sustainability is complex; thus, the concerns with regard to the issue of pellets are wide ranging and include the sources of wood fiber, possible better uses of logs, the impacts on forest ecosystems, impacts on soil and atmospheric carbon balance, and the time scales considered (Reijnders 2006, Marland 2010, Anonymous 2012, Haberl et al. 2012, Holtsmark et al. 2013, Lamers and Junginger 2013). The issue of the resource sustainability (wood from forests in the United States in this case) is not included in this analysis. Likewise, the potential for direct and/or indirect land use change or carbon balance is segregated from this analysis. These issues receive much discussion in the scientific literature, and some people consider them to be of preeminent importance in discussions of potential solid biofuel systems (Farrell and O'Hare 2008, Searchinger et al. 2008, Päivinen et al. 2012, Sikkema et al. 2014). However, in this analysis, we assume that the wood biofuel source has been deemed to be acceptable within a given renewable-energy policy framework.

The main goal of this article is to describe a method to adjust taxes or subsidies applied to solid biofuels to account for the embodied fossil carbon. To provide a context for our adjustment proposal, we assess three woody biomass scenarios based on their greenhouse gas (GHG) emissions. Our focus here is to illustrate how LCA methods could be used to account for differences in processing and transportation inputs to various potential biomass energy sources. This accounting system could potentially be included in developing and applying bioenergy programs that have been accepted after larger consideration of their sustainability and/or climate benefit. This analysis uses LCA principles and data. However, LCA is intended to be only one component of sustainability analysis (Curran 2013, Heijungs 2013).

Methods

In this article, we present three procurement paths (scenarios) to illustrate (1) that the amount of nonrenewable energy embodied in renewable (wood) energy systems can vary substantially (processing, e.g., pelletization and transport are particularly important variables) and (2) that the differences in carbon benefit for renewable energy sources can be accounted for by considering the embodied fossil energy, as calculated using life-cycle database information.

We assess and discuss three alternative procurement paths for green energy generation. These scenarios were developed to provide examples to illustrate the application of the accounting tool (see ''Finding 2'' below). The first scenario (''US pellets'') is an example of long-distance transport of relatively highly processed biomass energy (pellets) from the southeastern United States to Italy. The procurement path assumes green ''pulpwood'' as feedstock material for pellet mills in the southeastern United States, which are growing in number and scale (the recent new capacities exceed 1.5 million tons per year and are currently entirely for export) (Bonitz and Blair 2013).

The second scenario (''Slovenian pellets'') provides an example of relatively highly processed biomass (pellets) but with a relatively short transportation alternative of intra-EU energy provision from Slovenia to Italy. Both pellet scenarios assume bulk loads for commercial/industrial applications; no bagging steps were included. The final scenario (''Slovenian chips'') assesses the impacts of wood chips produced and used for energy in Italy as a minimally processed and local (relatively) bioenergy example. This scenario includes only in-forest chipping of trees and transport of the chips to the Italian market. This assumes that the local customer can use green (undried) chips in place of pellets.

Italy was selected as the example consumption point for the first two alternatives for several reasons. There is a potential for increased pellet use in the country. Flach et al. (2014) report that pellet consumption in Italy increased by more than 25 percent between 2009 and 2014, mostly for private residential and industrial boiler use. They also project that this growth will surge in the short term. While less than 10 percent of this consumption is of US pellets, Italy's reliance on US pellets has increased recently, a trend that is likely to continue (Flach et al. 2014). Also, Italy borders Slovenia and thus is a likely destination for pellet exports. Slovenia currently is Italy's largest supplier of fuel wood but only a minor source of pellets (Lamers et al. 2012). Italy also is a logical example of a consumer of pellets from the southern United States, given the demand for woody biomass for energy and the availability of some specific deep-sea ports (for the transshipment/handling of large-volume ocean ships).

The first two scenarios were developed to simulate potential sources of increased demand for pellets. As stated above, Slovenia is an obvious trade partner for Italy owing to its proximity to northern Italy, the region of the majority of pellet use. Slovenia also has a resource base that currently is underutilized (it is one of the most forested countries in the EU) and has an expanding pellet production capacity with little domestic consumption. Domestic pellet production was projected to reach 100,000 tons in 2013, representing almost 100 percent growth in the past 10 years (Krajnc et al. 2013). Tennessee (southeastern United States) has resource and production circumstances similar to those of Slovenia. The traditional forest products industries (lumber, plywood, pulpwood, and paper) in both areas have declined in the past decade (Bonitz and Blair 2013), and the gap between forest growth and wood harvest is substantial. This suggests that there is an opportunity for increased wood bioenergy production in both areas.

We calculated the GHG emissions (principally CO_2 from fossil fuel usage) resulting from pellet and wood chip harvesting, processing, and transport. Area-specific databases were used to provide data for ''processes'' within each scenario, even though this necessitated the use of different databases: the US LCI database (NREL 2012) for evaluating the long-distance pellet provision from the southeastern United States and the Ecoinvent database (Weidema et al. 2009) for EU pellet provision from Slovenia. The system boundaries were scenario specific and included forest operations, transportation, and processing (Table 1).

The inputs and emissions for each wood-to-energy scenario were calculated using GreenDelta OpenLCA software (GreenDelta 2013). LCIA was conducted using the TRACI model (Bare 2011). In order to compare wood fuel scenarios, the amounts of solid biofuel modeled in each scenario were adjusted to an amount with a gross heating value equal to that in 1 tonne of wood pellets (Table 2). Fossil coal was included as a nonbiofuel alternative (calculation included the fossil carbon emissions from mining, transport, and combustion).

Results

Finding 1: Different wood energy scenarios entail the use of different amounts of fossil fuels

There are substantial differences in the GHG emissions associated with the various wood-to-energy scenarios (Fig. 1). These differences are mostly the result of the electrical energy required for pelletizing and the diesel fuel required for transportation.

Harvesting and transporting the feedstock material for pellet production represents a relatively small portion of carbon emissions in the pellet scenarios. Both analyzed scenarios indicate a comparable minor portion of carbon emissions emitted by processes up to the forest road (26.5 and 19.3 kg CO_2 eq per tonne of pellets, respectively). The most important processes from a GHG emission perspective are pellet milling (which includes drying with fossil fuel energy) and long-distance ocean shipping. A substantial part is contributed by road (truck) transportation and, in the case of inner-EU procurement, by railway transportation to Italian markets. In the ''US pellets'' scenario, we assumed a long (600 km) train haul from the pellet plant to the port. This is a farther distance than most current pellet production is hauled but could become more realistic if export volumes increase. Regardless, this transportation component contributes relatively little to the total carbon emissions.

The low processing and transportation scenario evaluates domestic EU energy wood chip procurement. There is a significant difference in GHG emission in processes (forest

Table 1.—Unit processes used for modeling the various bioenergy options.[a]

	US pellets[b]	Slovenian pellets[c]	Slovenian chips[c]
Raw material supply	Forest operations (felling, delimbing, loading, skidding); 2.65 t of pulpwood (MC = 50%) (see Table 2)	Residual wood, hardwood, under bark, MC = 80%, at forest road; 2.65 t	Forest operation fuel consumption (felling, skidding, chipping) (see Table 2)
Raw material transport	Transport, combination truck, long haul, diesel powered; 100 km	Transport, lorry >16 t, fleet avg. 100 km	Transport, lorry >16 t, fleet avg. 100 km
Processing	Pelletizing, SE US/electricity power generated by mixed sources; 172.13 kWh/t (Jonker et al. 2014)	Pelletizing, Slovenia/electricity mix; 172.13 kWh/t	NA
Subsequent transport	Transport, train, diesel powered; 600 km Transport, ocean freighter, diesel powered; 8,253 km Transport, combination truck, long haul, diesel powered; 150 km	Transport, freight train; 450 km	Transport, freight train; 450 km

[a] MC = moisture content; NA = not applicable.
[b] Source: US life-cycle inventory database (National Renewble Energy Laboratory 2012).
[c] Source: Ecoinvent database (Weidema et al. 2009).

Table 2.—Input values for the three biofuel scenarios and the coal alternative.[a]

Energy source	GHV (MJ/t)[b]	Fuel needed for equivalent GHV to 1 t of pellets (t)	Wood raw material needed to produce biofuel option (t)
Wood (50% MC), chips	9,073	1.91	1.91
Pellets (SE US, Slovenia, Italy)	17,302	1.00	2.65[c]
Coal (fossil)	31,650	0.55	—

[a] GHV = gross heating value; MC = moisture content.
[b] Source: Forest Products Laboratory (2004).
[c] Source: Jonker et al. (2014).

operation and transportation) compared with the pellet scenarios. Chipping is conducted at the roadside as part of the forest operation process, which contributes additional GHG emissions to this step through fossil fuel consumption. Truck and train transportation is needed for moving the final product from the forest (Slovenia) to the point of energy consumption in Italy.

Despite the differences among the wood energy scenarios in their embodied fossil fuel inputs, they are all far superior to a pure fossil fuel alternative (e.g., coal; Fig. 2). Each generated megajoule of green energy reduces GHG emissions (70% in long-distance provision, 87% in the case of local EU provision, and 96% for domestic EU wood chip use, respectively). Because the amounts of each solid biofuel and the coal alternative were adjusted to provide an equivalent heating value, the potential energy output of each fuel is equivalent to the coal bar in Figure 2; thus, the net energy balance (energy out/energy in) is positive for the wood-to-energy scenarios shown here.

Finding 2: We can account for the fossil carbon embodied in wood energy systems

The data above could be used to discount a carbon credit payment for a solid biofuel in proportion to the amount of embodied fossil fuel (Table 3). Similarly, a carbon tax could be proportionally allocated to wood and fossil energy systems, according to the relative embodied fossil carbon emissions associated with each source. A CO_2 value of $20/tonne was used for illustration. Given the wide range of current carbon taxes in EU member countries (World Bank 2014), this value provides a reasonable, albeit conservative, representation of current carbon tax rates.

These examples illustrate that data from the LCA of the GHG emissions of wood energy systems can be used to adjust carbon credit or tax systems. This represents a holistic and consistent way to compensate for the embodied fossil carbon that exists within and that varies among bioenergy systems.

Discussion

Results from our example scenarios agree with other studies that suggest that local, less processed wood biofuels offer the greatest potential benefit in terms of mitigating climate change (Magelli et al. 2009, Dwivedi et al. 2011). The focus of this article is to use these examples to describe a method to account for variations in fossil energy inputs to potential solid biofuels (i.e., ‘‘Finding 2’’ above). As mentioned earlier, a version of such a system has been in place for a number of years in Belgium, where the Green Certificates awarded for electricity generation from biomass

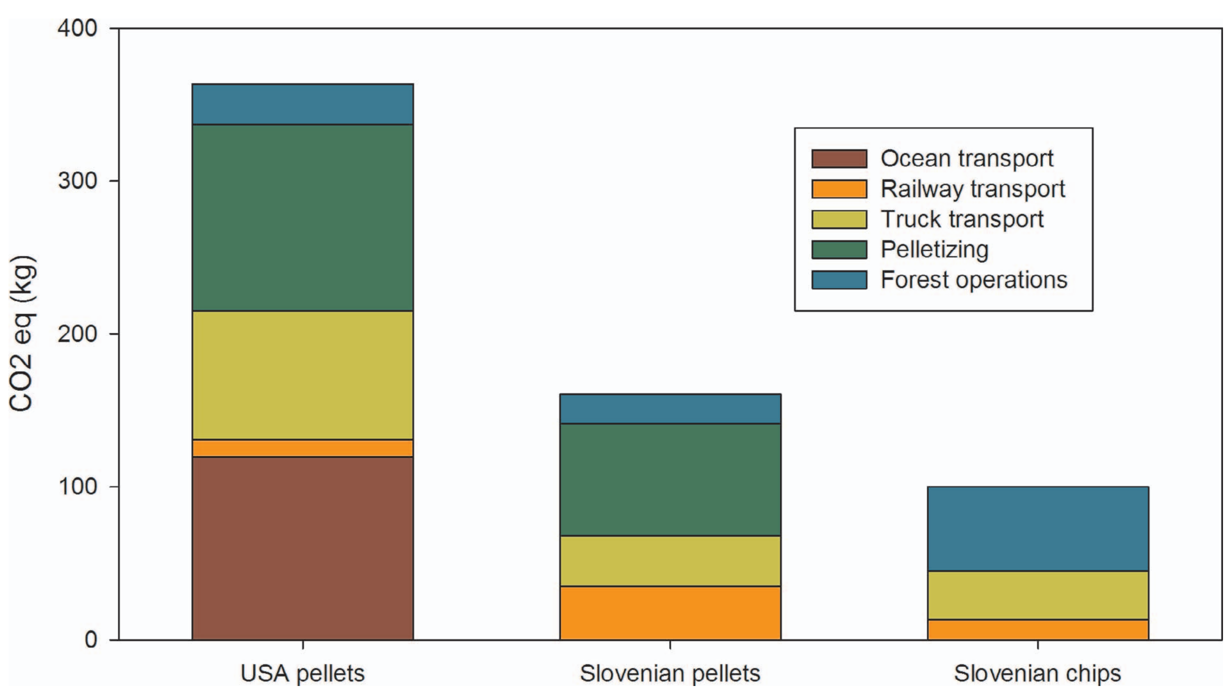

Figure 1.—Greenhouse gas impacts of inputs to the bioenergy scenarios. (Color version is available online.)

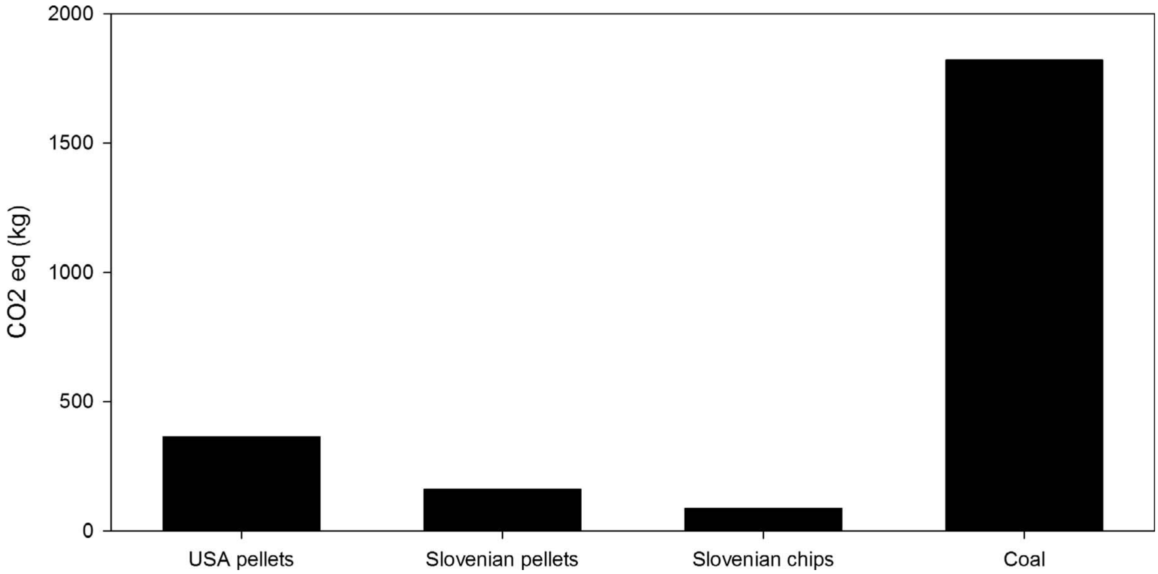

Figure 2.—Greenhouse gas impacts of bioenergy scenarios, with comparison to coal power plant electricity generation (NREL standards, electricity, and lignite coal at power plant). All scenarios are based on gross heating value equal to 1 tonne of pellets.

are reduced in proportion to the amount of fossil fuel used to prepare and transport the solid biofuel (Van Stappen et al. 2003). This type of approach is different from the ''threshold of qualification'' approach used, e.g., in the US Environmental Protection Agency's Renewable Fuels Standard, in which a biofuel option must provide a specified level of carbon savings but does not further distinguish between or rank qualifying fuels in terms of their potential to reduce GHG emissions. Our proposal could be applied to general carbon market transactions and is also a method that is increasingly practical, with the continued development and acceptance of LCA.

Potential wood energy sources exist in many parts of the world, and demand centers will vary with local changes in policy, alternative sources of energy, and other demand and supply factors. As illustrated here, transportation distances can influence the embodied fossil energy associated with a solid biofuel's source considerably; the proposed accounting scheme can easily accommodate various transportation modes and distances, using existing database information. Interestingly, other analysts have demonstrated the impact of carbon taxes as one policy alternative for addressing ocean transport to reduce GHG emissions. The World Wildlife Fund (2008) provides alternatives for reducing the effects of emissions from ocean transport and demonstrates the effects of various tax levels. Other processing steps are possible, such as torrefaction (Batidzirai et al. 2014) (i.e., ''black pellets'') or conversion to liquid fuels (Fan et al. 2011). These will change the fossil inputs and/or the net useful energy provided and thus alter the net carbon benefit. Similarly, applications of the fuel (e.g., electricity generation vs. combined heat and power) vary in their efficiency (BERC 2012). Such process and application variations are not included here; however, they could be relatively easily handled by comparing alternatives on the net energy provided rather than potential fuel value.

Environmental product declarations (EPDs) are standardized summaries of LCA data (ISO 2006a, Bergman and Taylor 2011) that are beginning to be required for some products in some jurisdictions. Product category rules (PCRs) outline the requirements for EPDs, and the accounting method proposed here could easily interface with EPD requirements if, as is usually the case, the PCR requires information on fossil fuel inputs and/or GHG emissions (Schenck 2013). The calculations for the embodied fossil energy credit reduction or tax on a solid biofuel could be based on the data in an EPD. The EPD requirement would ensure fair comparison among alternatives and could be used for additional considerations of sustainability.

Allocation is an important potential variable in LCA. In systems with more than one product, inputs and emissions may be ''allocated'' to the coproducts in proportion to their relative mass or value or by considering alternative routes for coproduct production (ISO 2006b). Allocation considerations can have important implications for the results of LCA of wood products systems, where multiple products are normal. For example, Reed et al. (2012) demonstrated the importance of allocation in systems producing pellets from hardwood flooring residues. In that system, the

Table 3.—Adjusted carbon credit or tax values for the various biofuel options.

Alternative	Embodied fossil energy (proportion of total fuel value), %	Adjusted credit ($) under a carbon credit system (nominal credit = $20/t)	Adjusted tax ($) under a carbon tax system (nominal tax = $20/t)
US pellets	20	16	4
Slovenian pellets	10	18	2
Slovenian chips	3	19.40	0.60
Coal	100	0	20

monetary value of the main product (flooring) is much greater than the residue that is used for pellet production, even though the mass is roughly equivalent. Thus, the allocation decision greatly influences the conclusions about the environmental impacts of the pellet product. In the analysis presented here, we have assumed that the production processes make only one product (wood pellets), and thus all of the associated environmental impacts (including fossil carbon emissions) belong to the wood pellet product. However, the ''pulpwood'' raw material (even if entirely converted to pellets) is often only one of a number of coproducts from a forest harvest, others being sawlogs, veneer logs, and specialty products. Some studies have demonstrated differences between using ''dedicated'' biomass energy resources or ''residues'' (Cherubini et al. 2009, Abt et al. 2012, Dwivedi et al. 2013). However, roundwood used for pellets may not fit well in either category, and thus allocation would be an important consideration, such as if a PCR were developed for wood pellets.

In this analysis, we explicitly set aside considerations of the resource sustainability and the carbon consequences of its harvest. These issues are complex and very difficult to quantify (Davis et al. 2012) and have been explicitly excluded in other analyses (Magelli et al. 2009, Pa et al. 2012). Dwivedi et al. (2014) included management variables in their examination of the implications of using American wood pellets as biofuel alternatives in Europe. Their study required 930 scenarios, but they concluded, as we have, that wood pellets offered environmental advantages over fossil fuel alternatives. As stated above, it is not our intention to develop a sustainability measurement for wood or other solid biofuels; rather, we propose a system for accounting for the fossil component in potential solid biofuel sources. The decision of whether a potential biofuel source is sustainable or otherwise acceptable is a larger question. Lal et al. (2011) discuss the difficulties in accounting for land use change and other variables and suggest the development of a broad range of sustainability indicators for biofuels. A number of studies and reviews have also been conducted on sustainability criteria and indicators for forest fuels (environmental, social, and economic) (Stupak et al. 2011).

Conclusions

Fossil fuels are required, in various amounts, for the production and transport of solid biofuels. The amounts of these embodied fossil fuels can be calculated using life-cycle methodology. Determining the sustainability or general acceptability of solid biofuels is a multidimensional challenge.

When considering that solid biofuels may replace not only coal but also partially (indirectly) natural gas, the savings on CO_2 emissions could be much more modest. The acceptability of substitution will then depend on market conditions and policy tools applied.

However, as a component of sustainable energy policy, we propose an accounting system based on CO_2 emission (LCA) inventories. Either carbon credits for using wood chips or wood pellets or taxes on the use of fossil fuels for energy can be imposed to adjust the embodied fossil fuel emissions.

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