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Life cycle inventory development for corn and stover production systems under different allocation methods

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ABSTRACT

Agricultural residues, particularly corn stover, are a promising feedstock for bioenergy systems. To analyze these systems in a life cycle framework, environmental impacts from cultivation and harvest must be allocated to the resulting products, corn grain and stover. This paper explores three approaches to allocation for corn and stover: economic and energy-based allocation, as well as a subdivision approach, which assigns to stover only those additional activities caused by its harvest.

This study develops a life cycle inventory for corn production based on average U.S. agronomic data and then applies the three allocation methods to produce a life cycle inventory for stover. This inventory contains over 1100 environmental flows and is available in the online Supplementary material. This analysis shows that economic allocation and subdivision assign the least impact to stover (14–15%), energy-based allocation the most (30%). One hectare of corn and stover production emits approximately 2.5 tonnes of carbon equivalent and requires approximately 23 GJ of fossil energy.

Value-based allocation methods, like energy and economic allocation, may be most appropriate when they reflect the goals of the production system. In addition, value-based methods are typically simple to apply, and thus may be more transparent for those interpreting a study. Subdivision, as applied in this study, reflects the consequences of changing the existing corn production systems, may require more data, and might be most appropriate for near-term prospective analyses; such as those that question whether adding cellulosic ethanol production to existing corn production systems yields environmental benefits. Thus, the selection of an allocation approach should hinge on the intent of the study.

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1. Introduction

Biofuels may offer an opportunity to reduce consumption of fossil fuels and greenhouse gas (GHG) emissions from the transportation sector, but they also have the potential for negative environmental and economic impacts. Production of biomass for biofuel feedstock represents a significant fraction of total environmental and energy impacts for biofuel production.

Agricultural residues may be a source of biomass for energy that avoids many of the unintended consequences of purpose-grown energy crops [1]. Corn stover (the above-ground remainder of the corn plant after grain harvest) appears to be a promising source of biomass for biofuel production, since it does not directly compete with food and is grown in large quantities during corn production. The U.S. produces well over 300 million tonnes of corn year^{-1} [2], and stover is produced at approximately a 1:1 ratio to corn on a dry-mass basis. Recent research has highlighted opportunities to use corn stover as a feedstock for chemical processes, including both biofuel and biopolymer production [3,4].

In the current corn production system, stover is rarely harvested and utilized, but when harvested, it becomes a co-product of the corn production system. In life cycle assessments (LCAs) of cultivation systems that produce multiple products, or co-products, by rotating crops or processing multiple parts of a plant for different uses, the whole system's impacts are typically allocated among co-products [5]. This need for allocation is not limited to cropping systems or agricultural products; in LCAs of any system that generates multiple products or services, some method for attributing environmental impacts to each co-product is required.

In this study the term *allocation* is used to describe all processes and methods that might be used to divide or otherwise attribute environmental impacts to a single co-product. This usage is broader than typical because, strictly speaking, allocation refers to division of the total environmental impacts between products in proportion to some formula. This definition would not include other common methods for treating co-products in LCA, such as subdivision and system expansion, which are often considered approaches that avoid allocation. Nevertheless, allocation is used here to refer to all methods for treating co-products.

Not surprisingly, allocation methodology can significantly affect the life cycle environmental impacts attributed to stover-derived products [6]. This paper describes three different approaches to allocating impacts from the corn and stover production system to stover alone, and produces life cycle inventories (LCIs) for the production of corn stover. The results of applying the three approaches are compared to evaluate their effect on the performance of corn stover as a biomass resource. This comparison helps characterize the variability introduced by the selection of a particular method for co-product treatment in LCA. In addition, this study creates LCIs for corn grain and stover production under different allocation approaches, which is available in the online Supplementary material.

2. Literature review

2.1. Co-product methods in LCA

Allocation of environmental impacts to valorized waste or residual streams has been recognized as a challenge by a wide range of researchers [7]. The International Standards Organization (ISO) promulgated the most widely acknowledged guidelines for LCA, the ISO 14040 and 14044 standards, which dictate a preference for avoiding allocation by subdivision or system expansion when assessing systems that produce co-products [8,9]. If allocation is required, because subdivision and system expansion are not possible, then value-based allocation of environmental flows using a physical basis such as energy content or mass is preferred. As a last resort, economic allocation may be used. Rather than using system expansion or subdivision, some LCA researchers have indicated alternative hierarchies to ISO for selecting methods for handling co-products, including designating system expansion as an allocation process, rather than as a process for avoiding allocation, and preferring economic allocation over other allocation approaches [10].

Ekvall and Finnveden discuss several allocation methodologies and conclude that the method should reflect a real-world causal relationship of the system under study [10]. Linking to a causal relationship helps improve an LCA's ability to answer relevant policy questions; in biofuel systems, energy could be preferred as a physical basis for allocation because energy production is the system's primary product. However, since corn and stover may be used for different purposes – corn grain for nutritional calories while stover for energy – a direct comparison based on energy may not be reasonable. In market economies, economic value may be even more important in shaping the formation of systems. However, because prices for any given product change, economic allocation can lead to temporal variability in the outcome of a study even when the production system remains unchanged. Despite the limitations of these two value-based allocation approaches, both are examined by this paper. Mass-based allocation for the corn production system is not considered. The economic and energy value for corn and stover is not strongly tied to their relative mass; a cultivated hectare typically produces an equal or greater mass of stover than corn, yet the energy content and economic value of the grain is typically much higher.

Previous research on corn stover for use as a bioenergy resource has largely adopted approaches that reflect a consequential LCA perspective [11,12]. In other words, the researchers assume a business-as-usual production system where stover is left unharvested, and then assign only the additional processes required due to stover harvest, such as stover collection activities and extra nutrient requirements resulting from stover removal. This consequential approach essentially describes our subdivision method. Recent scholarly literature seems to view consideration of market-mediated effects as a necessary element of consequential LCA [13]. This study does not consider market-mediated effects; however, the subdivision case described here models

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