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Food waste and the food-energy-water nexus: A review of food waste management alternatives

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ABSTRACT

Throughout the world, much food produced is wasted. The resource impact of producing wasted food is substantial; however, little is known about the energy and water consumed in managing food waste after it has been disposed. Herein, we characterize food waste within the Food-Energy-Water (FEW) nexus and parse the differential FEW effects of producing uneaten food and managing food loss and waste. We find that various food waste management options, such as waste prevention, landfilling, composting, anaerobic digestion, and incineration, present variable pathways for FEW impacts and opportunities. Furthermore, comprehensive sustainable management of food waste will involve varied mechanisms and actors at multiple levels of governance and at the level of individual consumers. To address the complex food waste problem, we therefore propose a "food-waste-systems" approach to optimize resources within the FEW nexus. Such a framework may be applied to devise strategies that, for instance, minimize the amount of edible food that is wasted, foster efficient use of energy and water in the food production process, and simultaneously reduce pollution externalities and create opportunities from recycled energy and nutrients. Characterization of FEW nexus impacts of wasted food, including descriptions of dynamic feedback behaviors, presents a significant research gap and a priority for future work. Large-scale decision making requires more complete understanding of food waste and its management within the FEW nexus, particularly regarding post-disposal impacts related to water.

Contents

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1. Introduction

Food waste is a social problem with far-reaching consequences, many of which are incompletely or inadequately characterized by current frameworks. For instance, while the impact of food waste to global food security may be theorized, the full range of socioeconomic and environmental consequences related to food production and waste are only beginning to emerge. Interactions among food waste, water and energy resources, environmental quality, and social justice suggest that broad-scale changes to food production and waste management may curb inefficiencies and externalities on many levels. Food waste is a complex problem, and one that likely requires a combination of technology-based solutions and direct public interventions and incentive structures to alter consumer disposal behaviors. This requires attention at three levels; first, at the individual unit of analysis, a focus on the behavior of consumers in response to regulatory incentives and self-motivated waste prevention actions; second, at the local level, a focus on the governance mechanisms that may minimize food waste by residential, commercial and institutional actors; and third, at higher levels of governance, investments to large-scale application of technological advancements seeking to capture waste and extract alternative forms of energy and materials. Food waste may never completely be eliminated, however there are significant opportunities to minimize waste and convert what is disposed into useful forms of energy.

Herein, we review and conceptualize the problem of food waste within the framework of the Food-Energy-Water (FEW) nexus. The objectives of this work are to (1) characterize food waste within the FEW nexus by defining potential fluxes of mass, energy, and water, (2) describe system dynamics, including feedbacks between human behavior and FEW impact, and (3) isolate gaps in current knowledge that must be addressed before the food waste-energy-water nexus can be fully operationalized in a quantitative sense.

2. Food waste background

2.1. Food loss and waste definitions

Definitions of food loss and food waste vary considerably (Table 1). Notably, items removed from the food supply chain during pre- and post-consumer phases are not consistently delineated within various definitions, suggesting need for internationally-recognized definitions of food loss and waste (Xue et al., 2017; Pink, 2016). The United Nations Food & Agriculture Organization (FAO) Global Initiative on Food Loss and Waste Reduction provides a framework defining food loss and waste, from which we adopt working definitions (FAO, 2014). Herein, *food loss* encompasses any decrease in quantity or quality of food through the food supply chain, for any reason. *Food waste* is a subset of food loss, and consists of material intended for human consumption that is not consumed. FAO acknowledges that the threshold at which food loss becomes food waste is not sharply defined (FAO, 2014). Food loss and waste have traditionally been differentiated based on the level at which edible food was removed from the supply chain, with food losses occurring earlier in the supply chain and food waste occurring in later stages, where consumer behavior is a factor (e.g. Parfitt et al., 2010). However, the definitions have become more nuanced, such that the root causes and motivations of actors involved in food waste are now the factor differentiating food waste from food losses. In general, food waste occurs due to some mismanagement in the food supply chain or the conscious decision to dispose of edible items. Food waste is largely seen as preventable food loss. For example, food that spoils due to temperature mismanagement during storage, spoilage due to harvest or processing inefficiency, or consumers throwing edible food away fit the definition of food waste. In light of the ambiguity between food loss and food waste, the term *food loss and waste* has been widely used by management entities. From a quantitative mass perspective, food loss and waste is equivalent to food loss, since food waste is a subset of loss. However, food waste directs emphasis to the differential processes and conditions that cause preventable food waste versus non-preventable food loss. This becomes problematic, however, when discussing treatment of food that is wasted (i.e. FAO definition) or disposed because it is inedible (i.e. European Commission (EC) definition). Therefore, the literature generally discusses food loss and waste collectively because of the inability to, even conceptually, separate them once they are disposed (Chaboud, 2017).

2.2. Scale of the food waste problem

It is challenging to estimate the amount of food waste and its global variability; as discussed above, available data often do not permit strict calculation of food waste. Available evidence suggests that food loss and waste represent a considerable portion of the global food supply, roughly one-third of food produced globally by weight, or one of every four kilocalories produced (FAO, 2011). Silvennoinen et al. (2015) found that in the Finnish food service system, around 20% of food served is wasted just in the processes of preparation and handling. Betz et al. (2014) estimated that storage, preparation, and serving losses, combined with plate waste in Switzerland, totaled around 18% of food grown. In the

Table 1
Definitions of food waste (adapted from Thyberg and Tonjes, 2016).

Organization	Definition
Food and Agriculture Organization of the United Nations	Removal of food which is fit for consumption from the supply chain, or removal of food which has spoiled or expired due to economic behavior, poor stock management or neglect
European Commission	Food (including inedible parts) lost from the food supply chain, not including food diverted to material uses such as bio-based products, animal feed, or sent for redistribution
United States Environmental Protection Agency	Uneaten food and food preparation wastes from residences, commercial and institutional establishments
US Department of Agriculture	A subset of food losses; occurs when an item still edible at the time of disposal is not consumed
World Resources Institute	Food fit for human consumption that is discarded—either before or after it spoils; either the result of negligence or a conscious decision to throw food away

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