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Temporal and geographic drivers of biomass residues in California

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ABSTRACT

Expanding bioenergy conversion and composting of organics can enable a near-term transition away from the landfilling, burning, and mismanagement of biomass residues. Strategic development of transportation, storage, and conversion infrastructure to enable this expansion requires detailed information on patterns and drivers of waste biomass production, quality, and geography that are currently lacking. This analysis contributes new geographic and temporal data on biomass residue availability for the state of California. Biomass residues are characterized for the year 2014 at the county- and month-scales for the agriculture, municipal, and forestry sectors in California, with values collected or estimated from numerous publications, databases, industry surveys, and methodologies. We present methods for developing supply scenarios out to the year 2050 that reflect anticipated changes in key environmental, market, and policy drivers. Our results suggest that biomass residue production could grow 16% by 2050 to 71 million tonnes of dry-matter per year, and that the co-processing of diverse high-moisture residue sources and storage of seasonally available low-moisture residues is needed to ensure adequate steady supply to bioenergy and composting facilities. Additional research and better reporting on organic waste management is needed to bound uncertainties regarding the response of residue production to market trends and recycling policies, and the influence of agricultural practices, plant selection, and climate impacts on residue yields.

1. Introduction

Characterizing biomass residue supply is central to understanding the role bioenergy and bioproducts can play in offsetting fossil fuel and petrochemical consumption in the United States (U.S.). Numerous biomass inventory assessments have demonstrated the diversity and long-term abundance of the resource at the national and regional scales (Turhollow et al., 2014; Perlack et al., 2011; Langholtz et al., 2016; Williams et al., 2015). At the same time, data on biomass production, quality, and availability have largely been reported or derived at the county and annual scales, while techno-economic analyses suggest that finer resolution spatial and temporal data are needed to estimate local opportunities, barriers, and costs for facility-level decision-making (Tittmann et al., 2010; Breunig et al., 2017; Jaffe, 2018; Xie et al., 2014). This study seeks to provide the spatial and temporal resolution needed for decision-making at the locality and facility-levels for California, while also providing broader perspectives relevant to state-level bioenergy production strategies.

Biomass residue inventories generally use residue yield factors to approximate waste production from databases reporting harvested acres or harvested produce, food and cotton productivity, forested land acres, and livestock and population head counts. Few studies have contributed to our understanding of the spatial heterogeneity and temporal variation in residue yields. In the absence of survey or other measured data, seasonal variation must be inferred from seasonal and quarterly reports on agriculture and municipal activities. Monthly production of food waste, from farm to plate, was estimated by Breunig et al. using seasonal and quarterly harvest and waste disposal reports (Breunig et al., 2017). Studies of seasonality for agriculture in California dating back to 1976 estimate monthly production of crop residues, and have been used extensively by subsequent resource assessments (Williams et al., 2015; Knutson et al., 1976; Knutson and Miller, 1982; von Bernath et al., 2004; Williams et al., 2008, 2006). Matteson and Jenkins estimated monthly production for several food processing residues in a 2007 analysis of food processor waste in California (Matteson and Jenkins, 2007).

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Past projections of biomass residues rely on high-level trends in human population, forest and agriculture land availability, with little variation in the yield factors used. Notable exceptions include a projection of biomass residues developed by the California Biomass Collaborative (CBC) out to 2020 (Williams et al., 2008), and a projection of municipal solid waste (MSW) disposal rates out to 2025 developed by the California Department of Resources Recycling and Recovery (CalRecycle) (Facility Information Toolbox CalRecycle, 2018). Projections of county-level forestry-, municipal-, and agricultural-residue production and consumption out to 2030 were developed as part of the *Billion-Ton Report* series in the US (Turhollow et al., 2014; Perlack et al., 2011; Langholtz et al., 2016). Published in a publically available database, this study is widely used to estimate biomass resources, despite limited characterization of drivers at local and regional scales.

In California, the management of biomass residues, which consists of the organic fraction of municipal solid waste (MSW), crop residues, food and fiber processing residues, and forestry residues, is evolving as the state aggressively pursues its 2020 goal of 75% diversion of MSW from landfills, pursues tighter restrictions on greenhouse gas (GHG) and criteria air pollutant (CAP) emissions, and seeks ways to reduce fire risks in forests and wildlands. Expanding bioenergy generation and composting of organics can complement source-reduction strategies to reduce landfill methane emissions and avoid the burning and mismanagement of municipal-, agriculture-, and forestry-organic wastes. However, careful estimation of net changes in emissions and other impacts is necessary, as residue collection, conversion, and byproduct management require energy and result in emissions. Consequential life-cycle assessment (LCA) (Finkbeiner et al., 2006) is a useful method for evaluating net changes in environmental impacts as a result of shifting organic residue management. Robust LCA of statewide scenarios requires detailed information on patterns and drivers of waste biomass quantity, quality, and geography that are currently lacking.

Our research builds on past work by deriving sub-annual biomass residue yields and developing new methods for constructing a comprehensive county-level biomass residue inventory for California. We also develop estimation and adjustment methods for missing or outdated information on seasonality, waste volumes, and management practices, and identify key uncertainties that could be reduced with additional survey or measured data (Williams et al., 2015; Breunig et al., 2017). Secondly, we identify socio-economic and environmental trends affecting biomass residue production and quantify expected future changes to develop scenarios for biomass residue availability out to 2050. Technical availability factors, which represent the fraction of residue that is potentially available for bioenergy after accounting for established uses, such as animal feed, and likely limitations to collection, are useful for gauging the impact of logistical challenges and market competition (Williams et al., 2015; Breunig et al., 2017). These factors are challenging to bound, as they are subject to unknown market dynamics and site-specific economics. For this reason, we limit the scope of this paper to the drivers of current and future gross biomass residue availability. Finally, we provide a discussion on the allocation of county-level residue inventory to sub-county locations that can be used to enable bioenergy/bioproduct facility siting research.

Our study ultimately provides a current inventory and set of projections for California with greater temporal, geospatial, and compositional specificity than any previous work, including sub-annual detail that is crucial in estimating energy generation potential and making strategic infrastructure investments. Our scenarios of residue availability for forestry, agri-industry, and municipal sectors out to 2050 provide the first estimate of biomass residues past 2030 that we are aware of. The methods documented here also can be applied more broadly across the U.S. and globally. California is a leader in developing and implementing environmental policy. Therefore, understanding opportunities and barriers to organic residue diversion in California can result in valuable insights for stakeholders across the U.S. and world.

2. Materials and methods

2.1. Sub-annual availability factors

When crops are harvested, there are typically three categories of biomass generated: marketable product (produce), culls, and residues. A crop is grown for specific portions of its biomass (fruit, seed, fiber, root etc.), however a plant requires additional biomass to support itself. The above-ground fraction of the plant that remains once the marketable product is harvested is referred to as residue, and part or all of this biomass may remain on the field to ensure soil health (Collins et al., 1992; Post and Kwon, 2000). Portions of the plant that are shed voluntarily by the plant (leaves) or removed to improve the health and yield of the plant (trimmings, prunings) are also referred to as residues. Produce left in the field or lost during processing are referred to as culls. In-situ culls can occur if inefficiencies in harvesting leave produce in the field, if produce is rejected for not meeting market standards, or in the case of orchards, if there is stress on the tree and fruit are dropped before they are ready to be harvested. Production of culls and residues from row crops will occur during harvest, while residue production from orchards and vineyards will occur with winter pruning, spring and summer trimming, and tree removal. Field residues will also be generated during harvest, and either densified and sold, or left on field for soil incorporation following the harvest season. Availability of total solids from forestry will depend on lumber mill practices, land accessibility and ownership, tree species and ecosystem needs, as well as other land and forest fire management considerations (Shinners et al., 2011; Thörnqvist and Jirjis, 1990).

This study relies on residue availability data collected or estimated at the finest temporal and spatial scales possible based on publicly-available datasets and guidelines. While not all biomass types showed significant variation in production at the sub-annual scale (e.g. food waste, slaughter waste), temporal variation is an important characteristic for most biomass residues (Table 1). We explore the consistency of temporal harvesting patterns by comparing historical data from the oldest and most recent USDA NASS surveys published; these include 1961 and 2006 for orchards and vineyards, 1978 and 2009 for fields crops, and 1978 and 2016 for row crops (SI Section 1.2) (USDA NASS, 2006). Harvesting dates are verified with University of California (UC) farming calendars and publications by the UC Agriculture and Natural Resources Extension (The California Backyard Orchard: Calendars, 2018). Changes of one month (28 days) or longer to the harvest start, end, or peak duration for individual crops are noted as possible adjustments that should be made to sub-annual availability factors used to model future biomass residue supply (results discussed in detail in SI Section 2.2). The start and end of harvest and duration of peak production are converted into monthly residue and cull production rates for all crops at either the regional or state level (Fig. 3).

Deviations from seasonal patterns in farming practices and production yields can be year-specific, impacted by disease, pests, or severe weather. Deviations can also span multiple years if they are the result of prolonged drought or multi-year pathogen infestations, with normal seasonal patterns resuming with normal conditions. Long-term changes in climate, soil, and market demand can shift temporal patterns in agricultural activities more permanently (Kukal and Irmak, 2018). New advances in farming and new technologies can also cause long-term shifts. For example, some crops are being harvested by machine instead of by hand, which can reduce the number of days required for harvesting, and thus lead to a shorter peak production period of waste biomass. Machine harvesting may also lead to fewer in-situ culls, as produce is collected without discretion in the field and then scrutinized at processing facilities (potentially increasing the amount of rejected produce at processing facilities).

Seasonality is less of an issue for MSW, although there may be some peaks in production. Fats, oils, and greases (FOG) tends to peak during holidays, and different regions may experience peaking in green waste