The Mushroom Sustainability Story:

Water, Energy, and Climate Environmental Metrics

March 2017 Report Prepared by:

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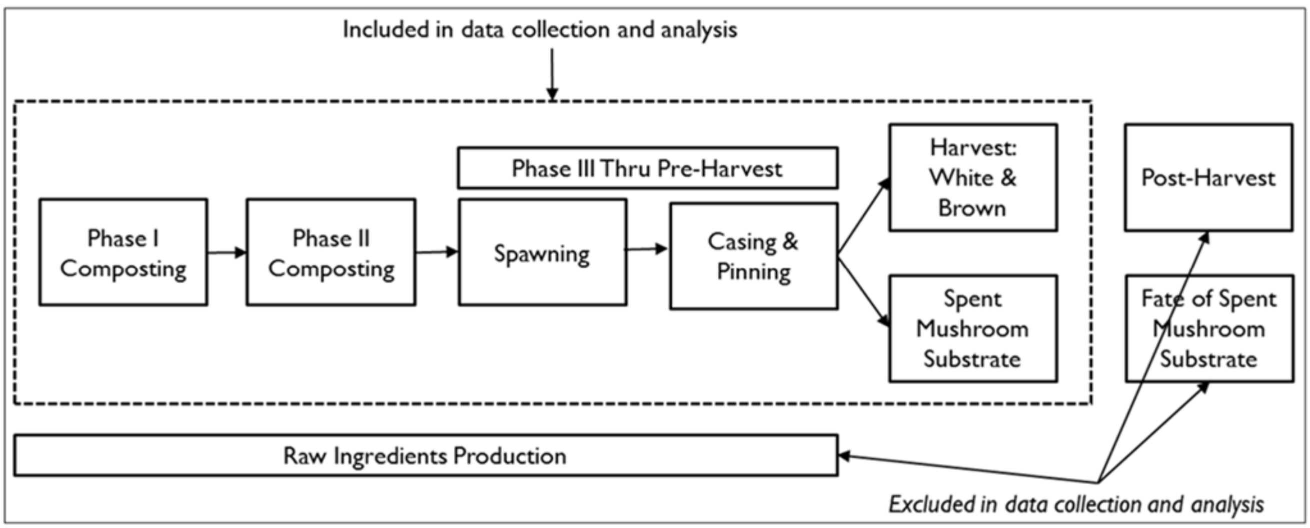
Introduction

This Mushroom Sustainability Report is the result of a two-year environmental footprint assessment initiative to document mushroom production environmental metrics including water and energy consumed per pound of mushrooms; and potential impacts on climate change as measured through the generation of CO_2 equivalents.[1] This report is part of broader sustainability initiative that includes a companion mushroom Life Cycle Assessment (LCA) research project led by Drs. Kendall and Winans with the Industrial Ecology Program at UC Davis. Environmental footprinting and LCA are two complementary approaches to analyze nature resources use and emissions along product supply chains.[2]

In this footprinting project, the data collection and analysis boundaries include Phase I, Phase II, Phase III through harvest, and embedded water in harvested mushrooms and spent mushroom substrate (SMS). Excluded in the analysis are resources used to produce and transport raw ingredients, post-harvest packaging, cooling, shipping, etc., and the fate of SMS (**Figure 1**). The UC Davis LCA research will include impacts from raw products and post-harvest.

Figure 1. Mushroom production phases, process flow, and data collection and analysis boundaries



A detailed online data collection tool that includes type of facility, facility size, water and energy use, and related production information from Phase I composting through harvest was designed based on

[1] CO_2 equivalents is a term for describing different greenhouse gases in a common unit.

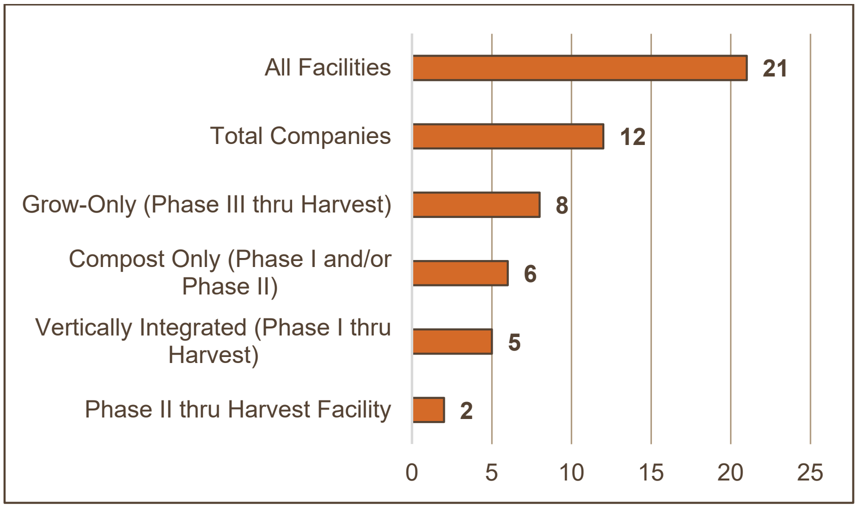
[2] Hoekstra, A.Y., 2015. *The sustainability of a single activity, production process or product*, Ecological Indicators, 57: 82–84.

literature review and more than twenty interviews with mushroom growers, packer/shippers, and industry experts.[3,4,5,6,7,8]

Facility and Production Information

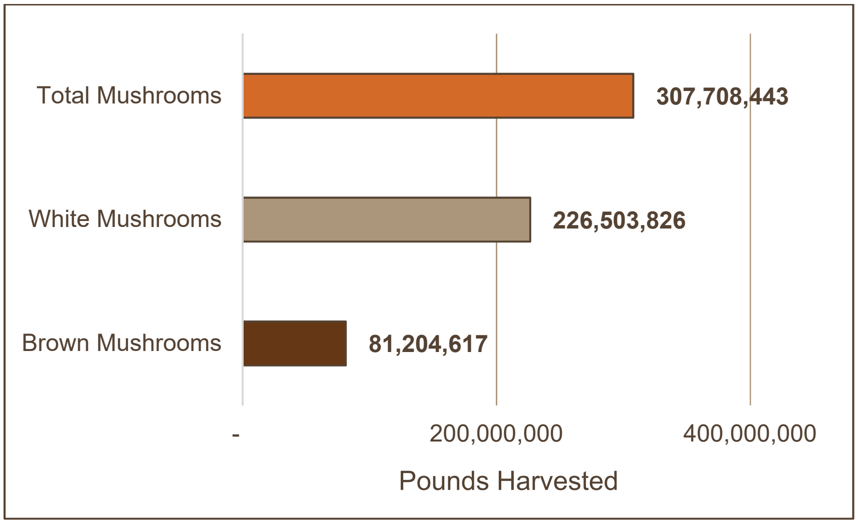
The information presented in this report was collected in 2016-17 and originates from twenty-one facilities in the US covering compost-only to fully-integrated compost to harvested mushroom operations (**Figure 2**).[9] The growing operations reported more than 300 million pounds of Agaricus mushroom production that represents approximately one-third of US mushroom production.[10] The data set includes more than 225 million pounds of white mushrooms representing close to 30% of US production and 81 million pounds brown mushroom that represents close to 50% of US production (**Figure 3**).[11]

Figure 2. Number of companies, facilities, and operational types included in the data set



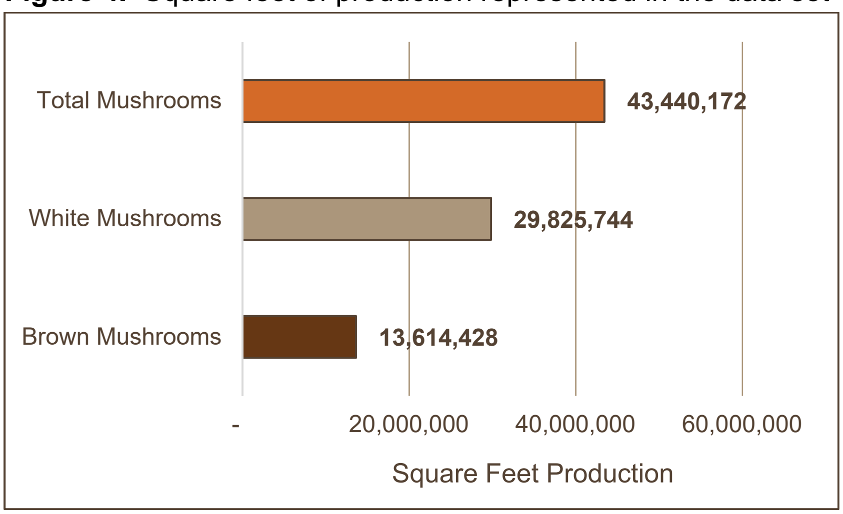
[3] Beyer, D. M., 2003. *Basic Producers for Agaricus Mushroom Growing*. Penn State College of Agricultural Sciences, Agricultural Research and Cooperative Extension.
[4] Coles, P.S., W. Barber, D. M. Beyer, et al., 2002. *Pennsylvania Mushroom Integrated Pest Management Handbook*. Penn State College of Agricultural Sciences, Agricultural Research and Cooperative Extension, Pennsylvania Department of Agriculture, and the American Mushroom Institute.
[5] Beyer, D. M., J. Pecchia, and L. Bertsch. 2008. *Mushroom Substrate Preparation Odor-Management Plan*. Penn State College of Agricultural Sciences
[6] Changing Tastes, 2014*. Fresh Mushroom Cultivation Sustainability Platform: People, Planet, Palate and Profit.* Changing Tastes.
[7] Penn State University and the American Mushroom Institute, 2010. *Mushroom Good Agricultural Practices Program*. Penn State University and the American Mushroom Institute
[8] Pennsylvania Department of Environmental Protection, 2012. *Best Practices for Environmental Protection in the Mushroom Farm Community*. Bureau of Waste Management, Division of Municipal and Residual Waste, Pennsylvania Department of Environmental Protection
[9] Data was collected from Canadian facilities but was not included in the analysis to ensure confidentiality.
[10] Agaricus mushrooms includes white and brown mushrooms (Portabello and Crimini).
[11] Mushrooms (August 2016) USDA, National Agricultural Statistics Service, ISSN 1949-1530.

Figure 3. Production in pounds for total (white + brown), white, and brown mushroom production included in the data set.



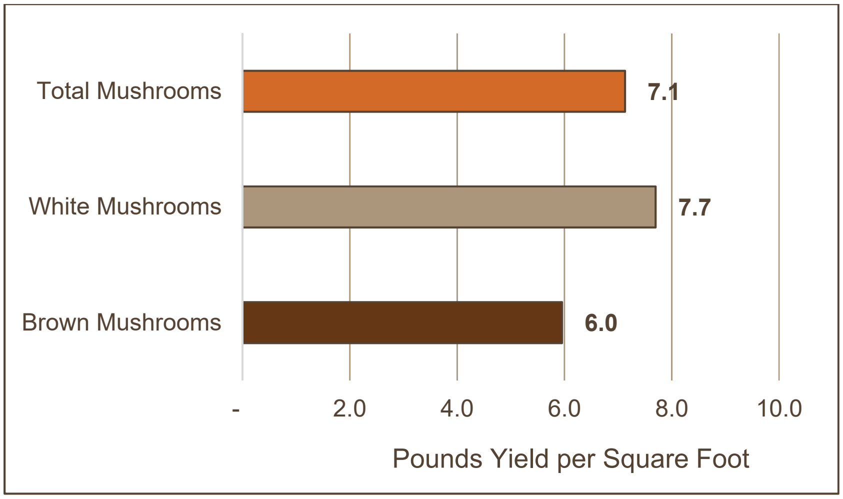
The production area covered more than 29 million square feet for white mushrooms and more than 13 million square feet for brown mushrooms (**Figure 4**).

Figure 4. Square feet of production represented in the data set



The average yields per square foot were calculated at 7.1 (± 1.0 SD) for all mushrooms, 7.7 (± 0.7 SD) for white mushrooms, and 6.0 (± 0.5 SD) for brown mushrooms (**Figure 5**). The USDA reported the average yield for all Agaricus mushrooms was 6.55 pounds per square foot in 2015-2016.[12]

Figure 5. Average yield per square feet of filling area for total (white + brown), white, and brown mushrooms in the data set

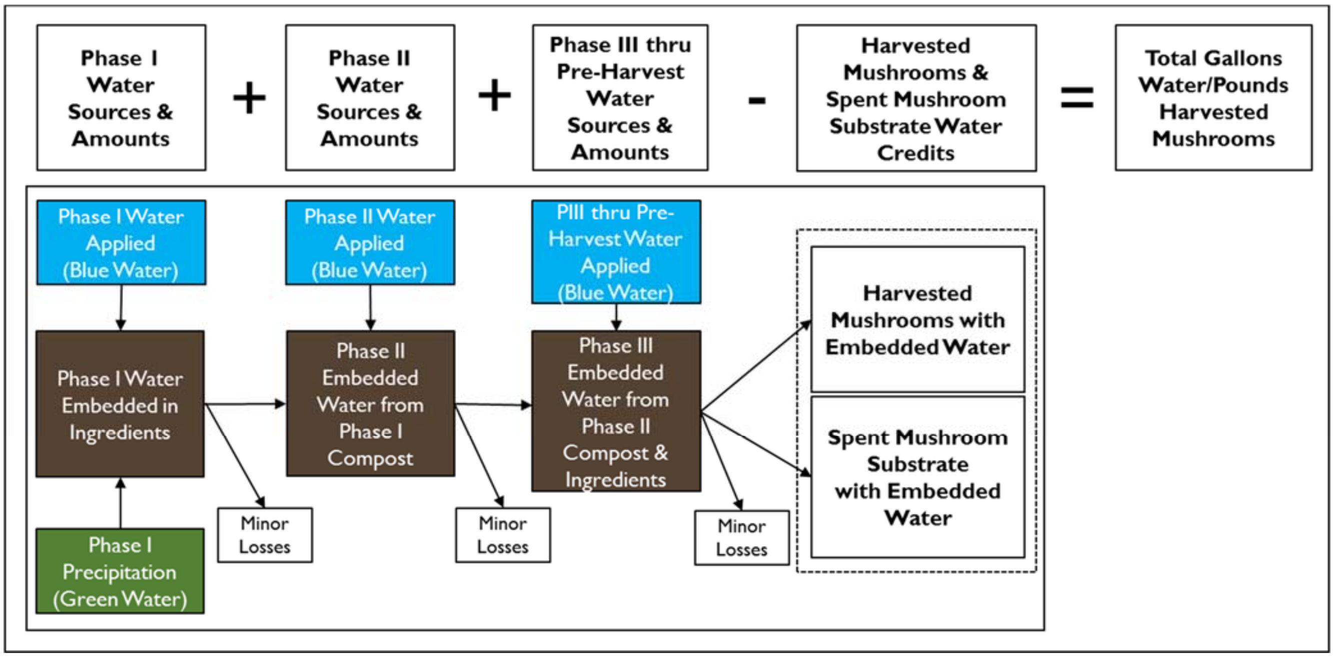


[12] Mushrooms (August 2016) USDA, National Agricultural Statistics Service, ISSN 1949-1530.

Water Footprint

The water footprint was determined based on the approach presented in Hoekstra et al., 2011 *The Water Footprint Assessment Manual: Setting the Global Standard*[13]. In this approach, water from precipitation is denoted as "green water" whereas applied freshwater is denoted as "blue water". The mushroom production water footprint was calculated by: (1) summing Phase I (freshwater applied, precipitation, and water embedded in ingredients), Phase II (freshwater applied and water embedded in ingredients); and Phase III through Pre-Harvest (freshwater applied and water embedded in ingredients); (2) subtracting the embedded water contained in harvested mushrooms and spent mushroom substrate; and then (3) dividing gallons of water per pounds of harvested mushrooms (**Figure 6).** The water footprint represents the average and standard deviation for gallons of water per pound mushrooms based on facilities that reported data from all phases. These facilities represent more than 10% of US mushroom production.

Figure 6. Process flow, water sources (i.e. green water and blue water), and amounts used to determine overall water footprint (gallons water per pound mushrooms)

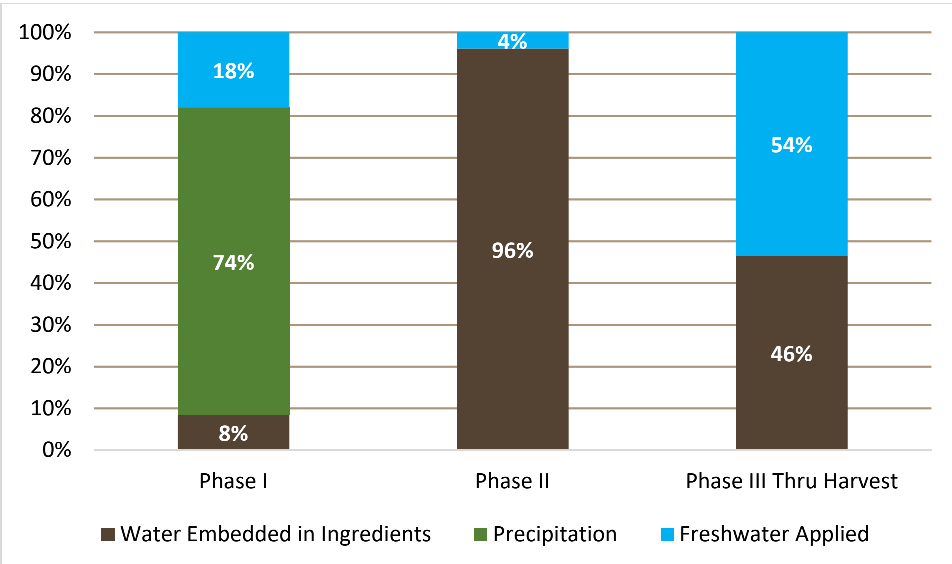


Water embedded in ingredients was calculated from data reported on total weight of ingredients and percent moisture. Water sources, amounts, and credit from spent mushroom compost were allocated by percent square foot production for white (68.7%) and brown mushrooms (31.3%). Water credit in harvested mushrooms and pounds yield are based on reported yields for white and brown mushrooms. Total mushrooms results combine white and brown data.

[13] Blue water includes fresh surface and groundwater applied. Green water is the precipitation on land that does not run off or recharge the groundwater as defined by Hoekstra, A.Y., Chapagain, A.K., Aldaya, M.M. and Mekonnen, M.M., 2011. *The Water Footprint Assessment Manual: Setting the Global Standard*, Earthscan, London, UK.

The sources of Phase I composting water were precipitation (74%), followed by fresh water applied (18%), and embedded water in ingredients (8%). Embedded water accounted for 96% of Phase II water by source. Freshwater accounted for 54% in Phase III through harvest (**Figure 7**)

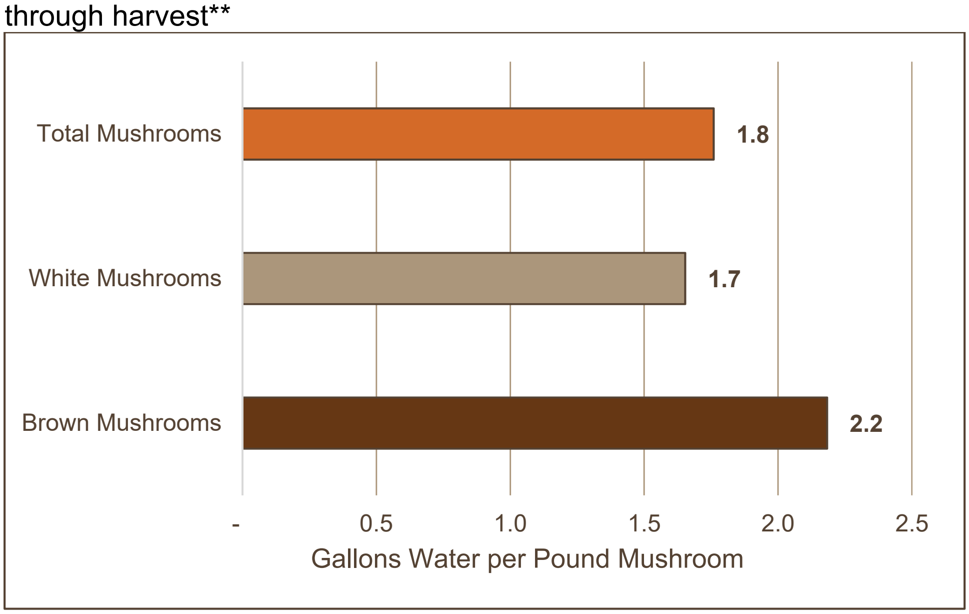
Figure 7. Percentage of freshwater (blue water), precipitation (green water), and water embedded in ingredients by phase.



The average gallons of water to produce one pound of mushrooms (**Figure 8**):

- 1.8 gallons per pound mushrooms (± 0.5 SD) for all mushrooms (white + brown);
- 1.7 gallons per pound mushrooms (± 0.4 SD) for white mushrooms; and
- 2.2 gallons per pound mushrooms (± 0.6 SD) for brown mushrooms.

Figure 8. Average gallons of water to produce one pound of mushrooms from Phase I composting through harvest**

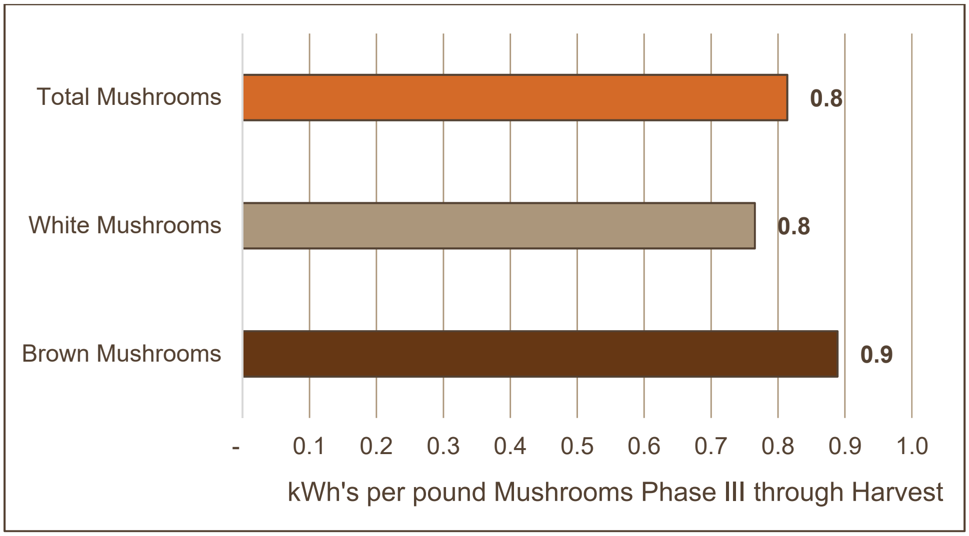


*** Includes credit from water embedded in harvested mushrooms and spent mushroom substrate*

Energy Footprint

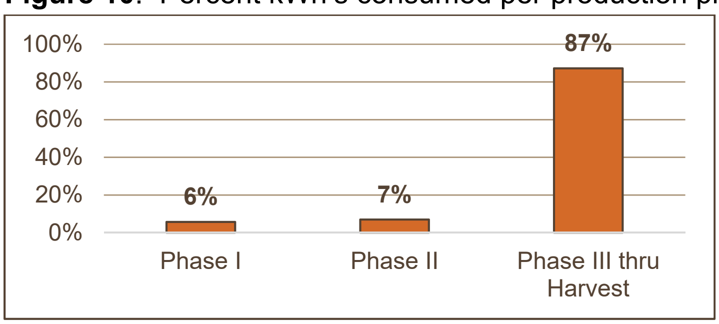
The average energy consumed during the Phase III through harvest processes were calculated by converting fuel use and type (e.g. diesel, natural gas, etc.) into kilowatt hours (kWh's) and adding kWh electricity use. The average kWh's for Phase III through harvest was calculated to be 0.8 kWh's per pound (± 0.2 SD) for all mushrooms, 0.8 kWh's per pound (± 0.2 SD) for white mushrooms, and 0.9 kWh's per pound (± 0.3 SD) for brown mushrooms (**Figure 9**). The averages are based on facilities that represent more than 30% of US mushroom production.

Figure 9. Average kWh's per pound of mushrooms produced for Phase III through harvest



To estimate the overall energy footprint (Phase I through harvest), the percent of kWh's per phase was determined using integrated facilities. Phase III through harvest accounts for more than 87% of the energy consumed in the mushroom production process (**Figure 10**). Using these percentages, the Phase III through harvest kWh's per pound of mushrooms presented in **Figure 9** were multiplied by a factor of 1.14 to account for the additional 14% energy consumed in Phase I and Phase II.

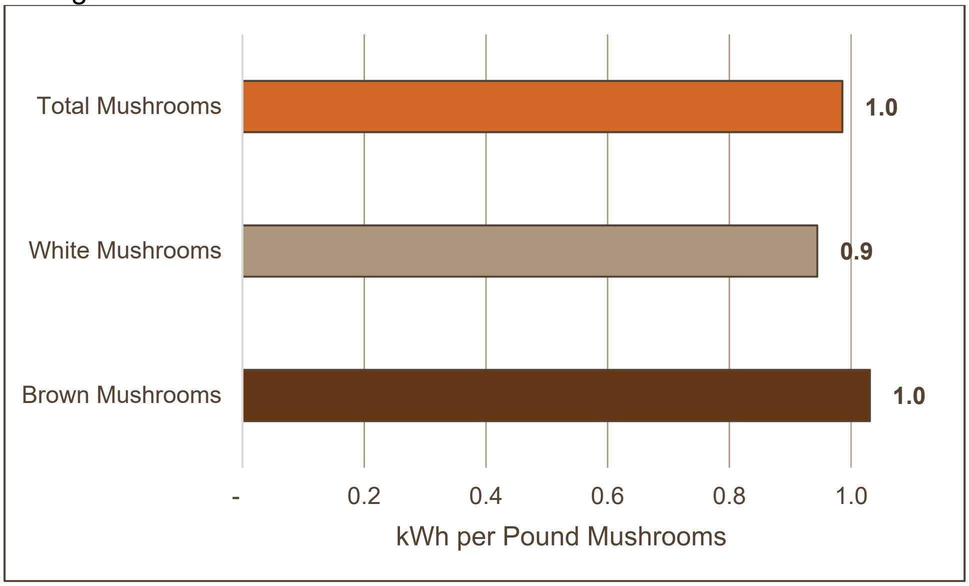
Figure 10. Percent kWh's consumed per production phase



The overall energy footprints for Phase I through harvest are estimated to be (**Figure 11**):

- 0.9 kWh per pound mushrooms (± 0.3 SD) for all mushrooms (white + brown);
- 0.9 kWh per pound mushrooms (± 0.3 SD) for white mushrooms; and
- 1.0 kWh per pound mushrooms (± 0.3 SD) for brown mushrooms.

Figure 11. Average kWh's of energy to produce one pound of mushrooms from Phase I composting through harvest



CO_2 Equivalents Footprint

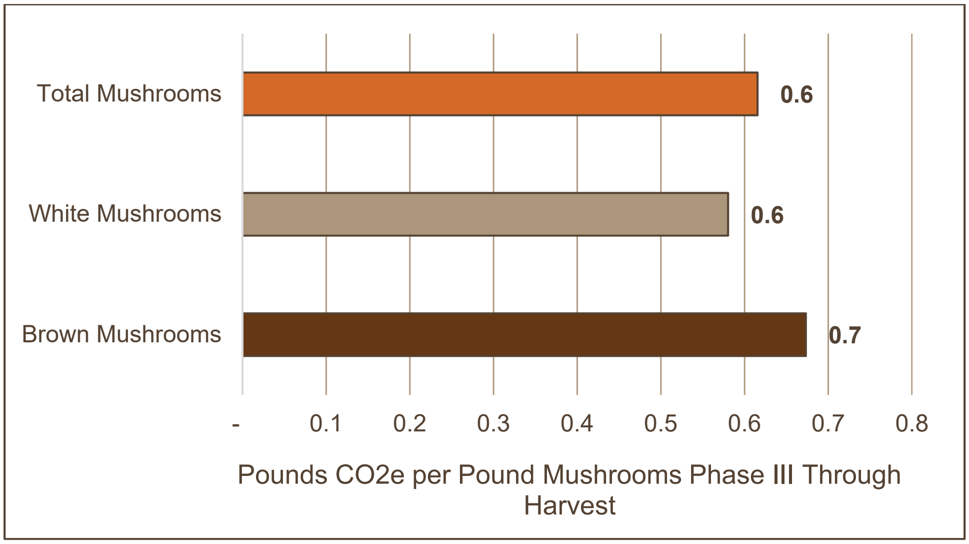
The CO_2 equivalents (CO_2e) information in this report is based on Scope 1 (all direct anthropogenic emissions) and Scope 2 emissions (indirect anthropogenic emissions associated with the consumption of purchased or acquired electricity, steam, heating, or cooling)[14]. The analysis excludes CO_2e from Scope 3 (all other indirect anthropogenic emissions that occur in the value chain. Examples of Scope 3 emissions include emissions resulting from the extraction and production of purchased materials and fuels).

CO_2e's were determine using Global Warming Potential (GWP) values from the IPCC Fifth Assessment Report, 2014 (AR5) for Carbon dioxide (CO_2), Methane (CH_4), and Nitrous oxide (N_20) released during the combustion of fuels by type (e.g. diesel, natural gas, etc.), loss of refrigerants by type (e.g. CFC-11, HCFC-22, etc.), and electricity used by regional electricity grid (eGrid 2014).[15]

The average pounds of CO_2e's generated during Phase III through harvest were calculated at 0.6 pounds CO_2e's per pound (± 0.2 SD) for all mushrooms, 0.6 pounds CO_2e's per pound (± 0.1 SD) for white mushrooms, and 0.7 pounds CO_2e's per pound (± 0.2 SD) for brown mushrooms (**Figure 12**).

[14] The Climate Registry, 2013. General Reporting Protocol Version 2.0. The Climate Registry;
[15] IPCC data source for AR5 values: https://www.ipcc.ch/pdf/assessmentreport/ar5/wg1/WG1AR5_Chapter08_FINAL.pdf (p. 73-79). Source of eGrid 2014 data https://www.epa.gov/energy/emissions-generation-resource-integrated-database-egrid

Figure 12. Average pounds CO_2e's per pound of mushrooms produced for Phase III through harvest



Phase III through harvest accounts for more than 90% of the pounds CO_2e's generated in the mushroom production process. To estimate the total CO_2e's for all phase, Phase III through harvest pounds CO_2e's per pound mushrooms were multiplied by a factor of 1.09 to account for the additional 9% CO_2e's generated in Phase I and Phase II. The overall CO_2e footprints for Phase I through harvest are estimated to be (**Figure 13**):

- 0.7 pounds CO_2e's per pound mushrooms (± 0.2 SD) for all mushrooms (white + brown);
- 0.6 pounds CO_2e's per pound mushrooms (± 0.2 SD) for white mushrooms; and
- 0.7 pounds CO_2e's per pound mushrooms (± 0.2 SD) for brown mushrooms.

Figure 13. Average pounds CO_2e's per pound of mushrooms produced for Phase I composting through harvest