Life Cycle Analysis Comparison of Organic and Conventional Blueberry Production

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I. Abstract

Current literature contains varying speculations regarding the sustainability of organic farming practices. Due to the low potency of pesticide used, it is speculated that organic crop production requires more land to produce a yield equivalent to that of conventional crop production which often involves heavy use of synthetic pesticides and fertilizers. This report discusses a life cycle analysis comparison of organic and conventional blueberry production with an objective of determining which method involves more energy intensive and carbon dioxide intensive processes, what the environmental impacts are for each system, and which unit processes are the most sensitive to fluctuations. The energy intensity and the carbon dioxide equivalent (CO2e) intensity will be analyzed based on the mass of one kilogram of blueberries as the functional unit. The method of approach is a meta-analysis or survey of current pure process-based life cycle studies. Our study mainly incorporates the work of Kumar Venkat of *CleanMetrics Corp.*, who performed a complete life cycle assessment of organic blueberry production versus conventional blueberry production.

According to Venkat, the energy intensity is 31.6 MJ/kg for conventional blueberries and 31.1 MJ/kg for organic; the CO2e intensity is 0.83 kgCO2e/kg for conventional and 0.72 kgCO2e/kg for organic. Other studies and databases, including TRACI, were used to determine the application rate of common fertilizers and pesticides in organic and conventional blueberry farming, along with the corresponding eco-toxicities of these chemicals. After considering application and leaching rates, the eco-toxicity potentials of conventionally used chemicals were found to be up to 26,063.672 times more eco-toxic to the environment than organically used chemicals. The eutrophication potential was also analyzed based on the amount of nitrogen from fertilizers and it was concluded that conventional blueberry systems use nitrogenous fertilizers that have a eutrophication potential that is 3.6 times higher than that for organic systems. Global warming potential was based on CO2e, so conventional yielded 0.83 kgCO2e/kg of blueberry, while organic yielded 0.72 kgCO2e/kg of blueberry, which was a difference of 0.11 kgCO2e/kg in GWP.

Cost effectiveness was also conducted to quantify the benefits associated with a 25% price premium on organic blueberries. It was found that if a consumer purchased a 0.2kg box of organic blueberries from the grocery store every week for a year then a total premium of $52 would have been paid. This premium would mean a reduction of 1.1 kgCO2e in that one year, as well as the use of fertilizers and pesticides that are far less toxic to the environment. If yield for organic and conventional production is equivalent, the data suggests that organic production is less energy intensive and less CO2e intensive than conventional blueberry production. However, these conclusions are highly sensitive to yield variation, as a reduction in organic production yield by more than 1.57% implies that organic production now becomes more energy intensive. Further sensitivity and uncertainty analysis shows that other energy consumptive and carbon emitting inputs that are highly sensitive to change are labor, sulfur, and nitrogen from fertilizers.

II. Goal and Scope

The goal of this report is to discuss the life cycle analysis comparison of organic and conventional blueberry production. Conventional farming often involves the use of synthetic fertilizers and toxic pesticides in order to maximize production yields. Organic farming avoids these synthetic chemicals, using only natural fertilizers and pesticides. Thus, organically grown products are considered more environmentally benign. However, studies suggest that organically grown fruit may require more land use, therefore having the possibility of being less sustainable

[Venkat 2007] [Parsons 2002]. Our project's objective is to determine the environmental impacts of growing blueberries organically versus conventionally. We plan to examine agricultural inputs and unit processes for organic and conventional blueberries to evaluate energy intensity and carbon dioxide intensity, as well as chemical toxicity, to make conclusions about the global warming potential, eutrophication potential, and eco-toxicity to air, water, and soil.

Because we do not have the means to gather primary data, we will be conducting a meta-analysis of existent blueberry life cycle studies. We will conduct an inventory analysis of direct inputs such as acreage, irrigation, wood waste, electricity, fuel, fertilizers, and pesticides, as well as some indirect inputs such as the transportation of fertilizers and pesticides to the farm. The total energy input (in MJ) and total carbon dioxide equivalent output (kg CO2e) for one year's worth of organic and conventional blueberry production on one acre of land will be assessed to evaluate global warming potential. The active ingredients of fertilizers, herbicides, and fungicides, along with varying leaching rates for organic and conventional blueberry production, will be used to make conclusions about the eco-toxicities to air, water, and soil. The application and leaching of nitrogen from fertilizers will be used to assess eutrophication potentials.

Other goals that this project aims to fulfill are to conduct a cost effectiveness analysis to determine the benefits per dollar of choosing to purchase organic blueberries over conventional blueberries. We also plan on analyzing uncertainty through the use of Monte Carlo analysis. The sensitivity of various parametric contributions to total energy and total CO2e emissions, such as yield, transportation, labor requirements, sulfur application, and nitrogen application will also be assessed.

III. Literature Review

In 1962, Rachel Carson's book *Silent Spring* spurred the environmental movement and brought to light the detrimental effects of pesticides on human health and ecosystems [Carson 1962]. Since then, increasing public awareness and concern over toxic chemicals contaminating food sources and the environment has caused demand for organic food items to grow rapidly. A study published in 2006 claims a 15-20% annual growth of the niche market for organic produce in general, and further looks at organic blueberry production in Georgia [Krewer, Walker 2006]. It is framed as a guide to farmers who may be considering switching from conventional blueberry production to organic production. The authors detail acceptable fertilizers and weed and pest control in organic farming. USDA-approved organic fertilizers that can provide necessary nutrients are also specified. According to this study, farmers are able to earn a 20-60% price premium on organic blueberries, depending on supply and demand in the market [Krewer, Walker 2006].

Another guide to organic blueberry production was released in 2011 by Cornell University [Graeper Thomas, Bucien 2011]. It outlines practices aimed at improving plant health and reducing pest problems in organic blueberry production systems. Other techniques for successful blueberry production are also discussed, including soil quality maintenance, crop rotation, plant variety selection, and irrigation. The study discusses fertilizer requirements for organic blueberries along with the various types of fertilizers that provide essential nutrients. Appropriate weed and pest control techniques include mulching, hand weeding, and natural herbicides like lemon grass oil. The fertilizers and pest controls from this guide are incorporated into our determination of which products are most essential to organic production. The information for the application of bone meal fertilizer, GreenMatch Ex herbicide, and Trilogy (neem oil) fungicide, were extracted from this study.

A study from the University of California Cooperative Extension proved to be very useful in our analysis. This study discusses the requirements and farming practices of organic blueberry production, and is intended to be relevant for Southern California county climates. The study considers an area of 10 acres of organic blueberry farmland and gives insight into the delicate system that must be maintained for a successful organic farm. According to this study, organic blueberry production requires slightly acidic soil, which is commonly maintained by sulfur application, as well as wood waste application which provides organic matter to the soil [Faber, Gaskell, et al. 2007, A]. This information is a critical part of our inventory analysis, and in addition, allowed us to find the application amount of agrilizer (fish fertilizer), nitrogen from fertilizers, iron chelate, citric acid, and copper champion fungicide applied to farmlands. The article also goes into a detailed description of the irrigation water required. The values are referenced in the base case meta-analysis table for organic blueberries [Table 1] and incorporated into the comparison of conventional vs. organic chemical eco-toxicities [Table 5].This study is also referenced by Kumar Venkat [Venkat 2007].

A corresponding article from the University of California Cooperative Extension discusses the input requirements, costs, and farming practices for conventional blueberry production. This article has been highly useful in finding application amounts of conventionally-used urea sulfuric acid fertilizer, ammonium sulfate fertilizer, iron chelate, Roundup spray (herbicide), Rovral (fungicide), and Kocide (fungicide) [Faber, Gaskell, et al. 2007, B]. The values are referenced in the base case meta-analysis table for conventional blueberries [Table 2]. This study is a parallel study of the aforementioned organic blueberry production study. This parallel study is ideal because it has allowed us to directly compare organic versus conventional inputs gathered from studies with identical assumptions and scopes. It is also referenced in Kumar Venkat [Venkat 2007]. It is interesting to note that some of the application rates mentioned in these UC studies of certain inputs are identical for both organic and conventional systems including iron chelate, wood waste, water, and gasoline and diesel to power equipment [Faber, Gaskell, et al. 2007, A][Faber, Gaskell, et al. 2007, B].

While researching existing life cycle data for organic and conventional blueberries, we came across a “cradle to farm-gate” study conducted by Kumar Venkat from *CleanMetrics Corp.* He compares twelve organic and conventional farming systems, including blueberries. This is the only complete life cycle analysis of organic and conventional blueberry production that we were able to access that quantified energy and embodied carbon. We contacted Kumar Venkat and he was kind enough to give us access to his inventory analysis tables. His study is currently in the process of being published. The data he gathered includes a comparison of application rates, energy inputs, and CO_2e emissions in organic and conventional blueberry production systems. His primary sources of data were the UC Cooperative Extension sources described above. Venkat utilized a software called *FoodCarbonScope* to translate inputs into CO_2e outputs (a software which we did not have the resources to access). The scope “cradle to farm-gate” implies that the data values used incorporate all inputs for production and farming. For example, direct fertilizer and pesticide application along with the indirect energy required to transport raw materials to the farm are included. However, any inputs required for harvest or post-harvest are not included. It is important to note that Venkat’s blueberry study is based on the production (in kilograms) for one acre during the year 2007. The yields for organic and conventional blueberries were the same, 6350.36 kg/acre, but the energy intensity and carbon dioxide equivalent intensity were both slightly higher for the conventional production [Venkat 2007]. The values from his study are referenced in Table 3 and further discussed in the inventory analysis section. Although organic blueberry production had lower energy and carbon intensities, Venkat emphasized that the organic production of several crops often correlates with higher energy inputs and embodied carbon. This can be due to lower organic production yield and energy and carbon intensive processes like transport of organic fertilizers and the manufacture of sulfur [Venkat 2007].

A Canadian study determined that organic blueberry production methods increase blueberry yield by 38% relative to conventional production [Parsons 2002]. The greater crop yield seen in organic blueberry production can be attributed to greater and more careful attention given by organic farmers to the growing process. However, the study performed by Venkat from *CleanMetrics Corp.* assumes that yield for organic and conventional blueberry production is equal [Venkat 2007]. We were able to find sources comparing crop yields for organic versus conventional fruit production; however it was difficult to find applicable information because many of these studies on organic yields were acquired from farms which used absolutely no pest control whatsoever. The USDA is currently undergoing a study that examines organic blueberry production and crop yields. However, this study will not be completed until the end of 2012 [Bryla 2012].

The assumptions and general conclusions of various LCAs on organic and conventional food products will be discussed briefly. One study concluded that shifting from conventional to organic production also leads to a shift in energy. This means that instead of using more energy for fertilizer production like in conventional systems, organic systems require more energy for machinery operation. This study also argued that organic systems tend to require more arable land [Roy, Nei et al. 2009]. In evaluating energy requirements and impacts, several studies use the mass of the product as the functional unit [Williams, Audsley et al. 2006] [Roy, Nei et al. 2009] [Antón, Montero et al. 2005]. This is justification for the use of mass of blueberries as a functional unit. Another study noted that additional indicators and considerations are necessary when evaluating the land use of agricultural systems, including soil erosion, soil organic matter, soil structure, and soil nutrients and pH [Mattsson, Cederberg et al. 2000]. Therefore, the conditions of the soil may very well alter the results of organic versus conventional cropping systems. One study revealed that shifting from conventional to organic farming reduces leaching of nitrogen by 50% [Berg, Haas et al. 2002]. This means lower nitrate concentrations in the soil and therefore lower leaching rates into water bodies. Based off of this study, in our analysis of eco-toxicities, we assumed that organic farm system inputs have a leaching rate 50% less than that of conventional system inputs. A German study revealed that by decreasing the use of mineral nitrogen fertilizer, organic farming could reduce the negative effects in impact categories of energy use, global warming potential, and groundwater contamination. It also demonstrated that acidification and eutrophication are generally higher for conventional intensive farming [Haas, Wetterich et al. 2001].

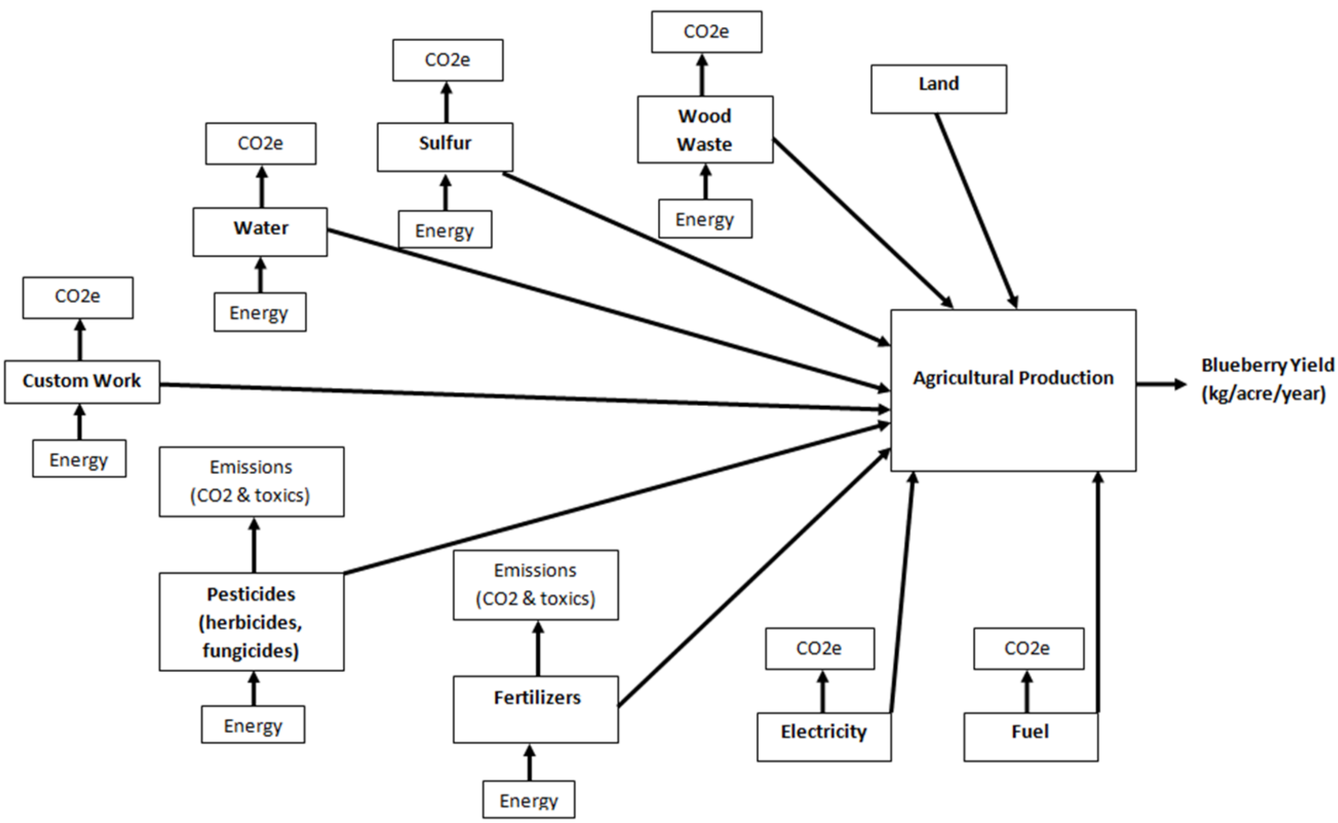
IV. Functional Unit, System Boundary and Flow Diagram, and Method

Our functional unit of analysis used in assessing inputs, outputs, and impacts is one kilogram of blueberries. For example, global warming potential is evaluated by comparing emissions of carbon dioxide equivalents per kilogram of blueberries. Most of the food LCA studies we analyzed used mass of the product as the functional unit, so we decided to use this as well. However, blueberries serve other functions other than providing a mass, so perhaps some limitations to the choice of our functional unit is that it does not encompass the different nutrients and levels of toxics within the blueberry itself.

Our system boundary will encompass direct and indirect inputs to agricultural production. These direct inputs include materials needed to produce the crop, such as pesticides, fertilizers, water, wood waste etc. Indirect inputs will consist of energy required for transportation of materials needed in agricultural production. Another example of an indirect input encompassed in our system boundary is energy required to power farm equipment. We will exclude harvest and post-harvest process, ie transportation to a distribution facility. We chose to exclude harvest and post-harvest processes because we assumed they would be very similar for both organic and conventional. The several unit processes within the system boundary that shall be analyzed are visible in the flow diagram in Figure 1**.** None of the unit processes within our flow diagram yielded multiple products so we did not have to undergo allocation procedures.

Our approach was to conduct a meta-analysis comparison on existent data from pure process life cycle analyses of organic and conventional blueberry production. We did not use any specialized software ourselves, but Kumar Venkat, whom we obtained the majority of our data from, used *FoodCarbonScope.* Other base case values were extracted from the UC Cooperative Extension studies and the Cornell production guide, all of which are discussed in the literature review above. We documented this meta-analysis in Excel.

Figure 1: Blueberry Agricultural Production Flow Diagram



V. Life Cycle Inventory Analysis

The inventory analysis tables are primarily based on a study by Kumar Venkat of *CleanMetrics Corp.* His study delivered base case values for total energy and carbon dioxide equivalents for various unit processes in organic and conventional blueberry production. Additional data regarding the application rates and types of specific pesticides, herbicides, fungicides, and fertilizers was extracted from the UC Cooperative Extension studies and Cornell University's *Production Guide for Organic Blueberries*. The data from these studies was incorporated into the base case and used to determine eco-toxicity and eutrophication potentials.

Several inputs for organic and conventional blueberry production are assumed to be equivalent. These include iron, wood waste, water, electricity, and fossil fuels for operating equipment. Inputs that differ across the two methods include the production and application of fertilizers, pesticides, herbicides, fungicides, and the amount of custom labor. Nitrogen from fertilizer application and production has higher embodied energy and embodied carbon, which is due to the fact that organic fertilizers often consist of larger doses of organic matter which require more energy for transportation than conventional chemical fertilizers. Conventional pesticide application and production requires 63.1 times the amount of energy and contains 62.2 times the amount of embodied carbon compared to organic pesticide application and production. More differences in embodied energy and embodied carbon for individual unit process inputs in organic and conventional production can be deduced by looking at Table 1 and Table 2. Based on the assumption that the yield for both conventional and organic is 6,350.36 kg/acre/year, the total energy intensity and carbon intensity is 31.6 MJ/kg and 0.83 kgCO2e/kg for conventional and 31.1 MJ/kg and 0.72 kgCO2e/kg for organic [Table 3], which are slight differences. However, as will be demonstrated later, if the organic yield were slightly lower, then it would have similar energy and carbon intensities to conventional.

Table 3: Base Case Energy Intensity and CO2e Intensity

Base Case:	Organic	Conventional
Embodied Energy (MJ/kg)	31.10427755	31.60475627
Total Embodied Carbon (kgCO2e/kg)	0.722562185	0.828667981

Table 1: Organic Blueberry Production Inventory Analysis Table

Unit process	Item	Quantity	Unit	Embodied Energy (MJ)	Carbon from all processes (except transportation) kgCO2e	Carbon from Transport kgCO2e	Total Embodied Carbon kgCO2e	Data Source
Fertilizer Production and Application	Agrilizer (liquid fish fertilizer)	4500	lbs/acre/year					[Faber, Gaskell, et al. 2007, A]
	Bone Meal	130	lbs/acre/year					[Graeper Thomas, Bucien 2011]
	Nitrogen (organic) from Fertilizers	122.4712	kg/acre/year	7440.77	258.38	307.01	565.39	[Venkat 2007] [Faber, Gaskell, et al. 2007, A]
	Iron Chelate	20	lbs/acre/year					[Faber, Gaskell, et al. 2007, A]
	Micronutrients - Iron from Iron Chelate	0.9072	kg/acre/year	24.55	1.73	0.14	1.87	[Venkat 2007]
Acidification	Sulfur Application	90.7194	kg/acre/year	11336.55	695.38	14.21	709.59	[Venkat 2007] [Faber, Gaskell, et al. 2007, A]
	Citric Acid	780	lbs/acre/year					[Faber, Gaskell, et al. 2007, A]
Pesticide Production and Application	Pesticide Formulation - Wettable Powder	0.9072	kg/acre/year	9.75	0.56	0.14	0.7	[Venkat 2007]
Herbicide Production and Application	GreenMatch EX	5	gallon/acre/year					[Graeper Thomas, Bucien 2011]
Fungicide Production and Application	Trilogy							[Graeper Thomas, Bucien 2011]
	Copper Champion	2	lbs/acre/year					[Faber, Gaskell, et al. 2007, A]
	Fungicide - active ingredient	0.6985	kg/acre/year	270.58	17.85	0.11	17.96	[Venkat 2007]
Wood Waste	Wood Waste (10 tons)	9072	kg/acre/year	142567.6	35.33	494.15	529.48	[Venkat 2007] [Faber, Gaskell, et al. 2007, A]
Irrigation	Water (24 acre-inches)	2466000	liters/acre/year	449.17	25.23		25.23	[Venkat 2007] [Faber, Gaskell, et al. 2007, A]
Energy: Electricity Demand	Electricity	372.2674	kWh/acre/year	3212.07	180.45		180.45	[Venkat 2007]
Energy (fossil fuel demand for	Gas (50.46 gal)	191	liters/acre/year	7258.83	487.81		487.81	[Venkat 2007] [Faber, Gaskell, et al. 2007, A]
	Diesel (3.78 gal)	14.3	liters/acre/year	609.24	46.17		46.17	[Venkat 2007] [Faber, Gaskell, et al. 2007, A]
Labor	Costs of Custom Work	31091	$	24344.25	1206.33		1206.33	[Venkat 2007]
Gaseous Waste	Carbon Dioxide	0.2944	kg		0.29		0.29	[Venkat 2007]
Soil Emissions	N20 from nitrogen/urea				817.26		817.26	[Venkat 2007]
Totals:				**197523**	**3772.77**	**815.76**	**4588.53**	[Venkat 2007]

Table 2: Conventional Blueberry Production Inventory Analysis Table

Unit process	Item	Quantity	Unit	Embodied Energy (MJ)	Carbon from all processes except transportation kgCO2e	Carbon from Transport kgCO2e	Total Embodied Carbon kgCO2e	Data Source
Fertilizer Production and Application	Urea Sulfuric Acid	1645	lbs/acre/year					[Faber, Gaskell, et al. 2007, B]
	Ammonium Sulfate	115	lbs/acre/year					[Faber, Gaskell, et al. 2007, B]
	Nitrogen (synthetic) from Fertilizers	219.8812	kg/acre/year	7052.56	258.49	104.39	362.88	[Venkat 2007]
	Iron Chelate	20	lbs/acre/year					[Faber, Gaskell, et al. 2007, B]
	Micronutrients - Iron from Iron Chelate	0.9072	kg/acre/year	24.55	1.73	0.14	1.87	[Venkat 2007] [Faber, Gaskell, et al. 2007, B]
Acidification	Sulfur Application	162.0575	kg/acre/year	20249.91	1242.12	25.39	1267.51	[Venkat 2007]
Pesticide Production and Application	Pesticide Formulation - Miscible Oil	4.536	kg/acre/year	575.89	40.06	0.71	40.77	[Venkat 2007]
	Pesticide Formulation - Wettable Powder	3.6288	kg/acre/year	38.99	2.23	0.57	2.8	[Venkat 2007]
Herbicide Production and Application	Roundup spray	1	gallon/acre/year					[Faber, Gaskell, et al. 2007, B]
	Herbicide -active ingredient	1.6975	kg/acre/year	999.77	60.56	0.27	60.83	[Venkat 2007]
Fungicide Production and Application	Rovral	2	lbs/acre/year					[Faber, Gaskell, et al. 2007, B]
	Kocide	6	lbs/acre/year					[Faber, Gaskell, et al. 2007, B]
	Fungicide - active ingredient	2.5492	kg/acre/year	987.45	65.14	0.4	65.54	[Venkat 2007]
Wood Waste	Wood Waste (10 tons)	9072	kg/acre/year	142567.6	35.33	494.15	529.48	[Venkat 2007] [Faber, Gaskell, et al. 2007, B]
Irrigation	Water (24 acre-inches)	2466000	liters/acre/year	449.17	25.23		25.23	[Venkat 2007] [Faber, Gaskell, et al. 2007, B]
Energy: Electricity Demand	Electricity	372.2674	kWh/acre/year	3212.07	180.45		180.45	[Venkat 2007]
Energy (fossil fuel demand for combustion in equipment)	Gas (50.46 gal)	191	liters/acre/year	7258.83	487.81		487.81	[Venkat 2007] [Faber, Gaskell, et al. 2007, B]
	Diesel (3.78 gal)	14.3	liters/acre/year	609.24	46.17		46.17	[Venkat 2007] [Faber, Gaskell, et al. 2007, B]
Labor	Costs of Custom Work	21297	$	16675.55	826.32		826.32	[Venkat 2007]
Gaseous Waste	Carbon Dioxide	0.36	kg		0.36		0.36	[Venkat 2007]
Soil Emissions	N20 from nitrogen/urea				1364.32		1364.32	[Venkat 2007]
Totals:				**200702**	**4636.32**	**626.02**	**5262.34**	[Venkat 2007]

VI. Life Cycle Impact Analysis

Eco-Toxicity

One of the focuses in our study is to assess the eco-toxicity potentials to air, water, and soil based on application and leaching rates of fertilizers and pesticides. To obtain data on the sorts of pesticides and fertilizers being used in organic and conventional blueberry production, the OMRI Products List, the Production Guide by Cornell University, and the UC Cooperative studies were thoroughly examined.

After obtaining data on application rates, MSDS sheets were used to determine percentages of active ingredients in individual products; thus the application of the active ingredient itself could be determined. The active ingredients for each product are listed in Table 4. We derived eco-toxicity potentials to air, fresh water, and soil from the TRACI database [TRACI 2011] for each active ingredient. TRACI gives eco-toxicity values per kilogram of substance in the environment but because a fraction of the substance actually reaches its target and is incorporated into it while the other fraction enters the environment through soil, water, or air, leaching rates need to be considered. Because one study argued that nitrogen leaching rates are 50% less for organic production than for conventional [Berg, Haas, et al. 2002], the assumption was made that herbicides and fungicides would also leach 50% less for organic systems. Thus an arbitrary leaching value was assumed for conventional and an arbitrary leeching value that was 50% less than conventional was assumed for organic. The leaching values for the active ingredients in conventional and organic input products were then used to determine the ratios of eco-toxicities of conventional inputs to eco-toxicities of organic inputs. The products compared and the ratios are displayed in Table 5.

As shown, the eco-toxicities of conventional chemicals used in blueberry production are an extremely large order of magnitude greater than that of organic production. Conventional chemicals (with application rate and leaching taken into account) are up to 26,063.672 times more eco-toxic. The only conventional chemical that had a lower eco-toxicity value compared to the organic alternative (GreenMatch Ex) was Round-Up. All other conventional chemicals had eco-toxicities that were greater than their organic alternatives by factors ranging from 6.003 to 26,063.672.

Table 4: Active Ingredients in Fertilizers, Herbicides, and Fungicides

Active Ingredients

	Conventional Input	Organic Input
Fertilizers	In Urea Sulfuric Acid: 49% sulfuric acid	In Agrilizer: 3% phosphoric acid
Herbicides	In Roundup: 41% glyphosate isopropylammonium	In GreenMatch Ex: 55% d-limonene
Fungicides	In Rovral: 41.6% Iprodione	In Trilogy: 1400 ppm Azadirachtin
Fungicides	In Kocide: 77% copper hydroxide	In Copper Champion: 77% copper hydroxide

Table 5: Eco-Toxicity and Eutrophication Ratios

Ratio of Conventional vs. Organic (Assuming 50% Lower Leaching Rate for Organic Production)

		Eco-Toxicity to Air	Eco-Toxicity to Water	Eco-Toxicity to Soil	Eutrophication to Water
Fertilizers:	Urea Sulfuric Acid vs. Agrilizer	2888.991	10956.736	3381.114	n/a
Herbicides:	Roundup vs. GreenMatch Ex	26063.672	0.959	160.737	n/a
Fungicides:	Rovral vs. Trilogy	2196.895	470.657	4156.246	n/a
Fungicides:	Kocide vs. Copper Champion	6.003	6.003	6.003	n/a
Nitrogen Application:	Conventional vs. Organic	n/a	n/a	n/a	3.591

Eutrophication

Another impact category that was analyzed was eutrophication. Eutrophication potential determinations were based on the different nitrogen application from fertilizers and on the assumption that organic leaches 50% less nitrogen than conventional. Table 5 shows that conventional nitrogen application had eutrophication potential 3.6 times greater than that of organic nitrogen application. Although nitrogen is an essential nutrient for plant growth, the application of nitrogen fertilizers may lead to nitrogen leaching into the environment in the form of nitrates into the soil and water and nitrous oxide emissions into the atmosphere. Nitrate leaching can lead to algal blooms and public health effects, while nitrous oxide may contribute to global warming since it is a greenhouse gas [Vano 2009].

Global Warming Potential

The third impact category that was analyzed was global warming potential (GWP). This analysis is based on the total carbon dioxide equivalent emissions for each conventional and organic blueberry production systems. Table 6 below shows the GWP for each and it demonstrates that conventional has a GWP that is 1.147 times more than that of organic.

Table 6: Global Warming Potential

Global Warming Potential

	kgCO2e/kg of blueberries
Conventional	0.8287
Organic	0.7226
Ratio (Conv:Org)	1.147

VII. Cost Effectiveness Analysis

On January 31st 2012, our group went to Ralph's Fresh Fare to investigate the price differences in conventional and organic blueberries. We purchased 0.2 kg of organic blueberries for $4.99 and 0.2 kg of conventional blueberries for $3.99. This price difference represents a 25% premium on organic blueberries. Based on the assumption that a consumer purchases 1 box of blueberries per week over the course of a year (52 weeks), the total amount of blueberries purchased would amount to 10.4 kg. Given the 25% price premium, represented by $1 per box of blueberries, a consumer would spend an additional $52 in a year to purchase organic. This dollar amount represents the total costs of purchasing organic blueberries.

A cost effectiveness analysis of purchasing organic blueberries over the course of a year reveals that there is a reduction in CO2e emissions of 1.1 kg/yr for spending an additional cost of $52/yr. In a comparison of fertilizers, the active ingredient used in conventional farming (Urea Sulfuric Acid) is 10,956.7 times more toxic to water than the active ingredient in organic fertilizer (Agrilizer) [Table 5]. This means that an additional cost of $52 for purchasing organic is associated with a fertilizer that is 10,956.7 times less toxic to water than the conventional fertilizer. Similarly, an additional $52/year to purchase organic blueberries means an herbicide that is 26,063.7 times less toxic to air is used. A fungicide that is 4,156.2 times less toxic when released into soil is used in exchange for the $52 price premium associated with purchasing organic blueberries. Finally, an additional cost of $52 for organic blueberries equates to the use of nitrogen fertilizers that have 3.6 times less eutrophication potential to water.

VIII. Sensitivity and Uncertainty Analysis

Data Analysis

For our analysis of compiled data, we conducted a sensitivity and Monte Carlo analysis for the outputs of carbon dioxide equivalent emissions and energy inputs. These methods of analysis were conducted for both organic and conventional blueberry production. Using the data we gathered from base case studies, we inputted values and ran the simulations using Excel. A few limitations were a result of missing and incomplete data from our base case studies. For this reason, we decided to focus on those unit processes that could be compared between organic and conventional blueberry agricultural production. Processes that yielded the same values were excluded in our analysis, as any results would be inconclusive.

Organic

In running a sensitivity analysis for the output of energy (MJ/kg of blueberry), we evaluated labor, sulfur application, nitrogen fertilizers, fungicide application, and pesticide formulation as our different inputs. The same inputs were used for both organic and conventional blueberries for the sake of consistency. It is also important to note that we were able to include labor in our analysis. This specific unit process could be accounted for because different machinery and contractors are used contingent upon the type of crop production. These factors were accounted for and summarized for us in our base case studies.

Results for sensitivity analysis indicate that labor was the most sensitive energy input for organic blueberry production [Figure 2]. This is most likely a result of more attention and work required for producing organic crops. Previous research also indicates that some growers will use outside contractors and machinery. Similar results were shown when running a sensitivity analysis for the output of carbon dioxide equivalent emissions [Figure 3]. Labor intensity for organic crop production requires the use of different machinery that emits more carbon dioxide equivalent emissions. Thus, researchers conducting future studies on the energy and carbon intensity of organic blueberries should be thorough in collecting data for labor due its high sensitivity relative to other inputs. Sulfur application and nitrogen from fertilizers are also sensitive parameters.

Figure 2: Organic Energy Sensitivity Analysis

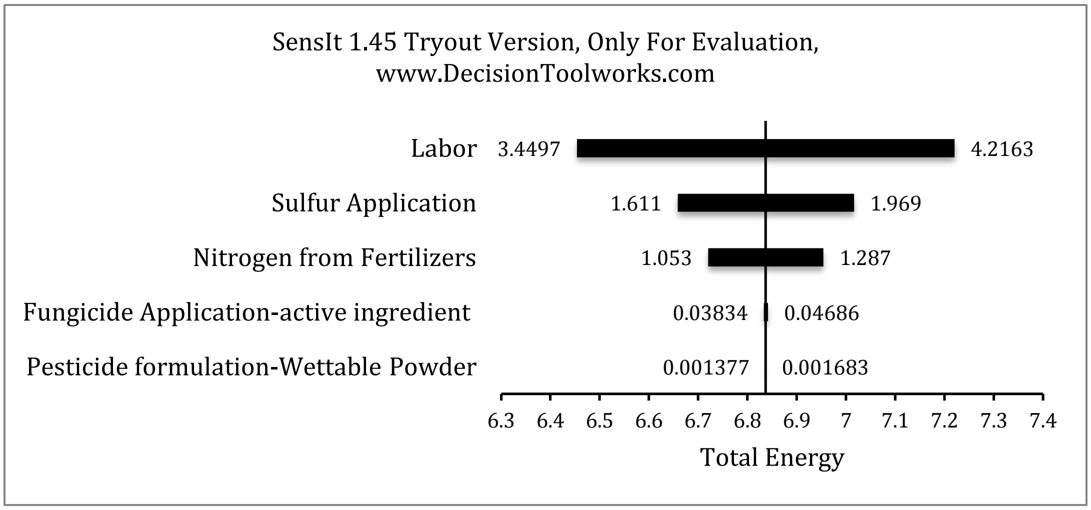
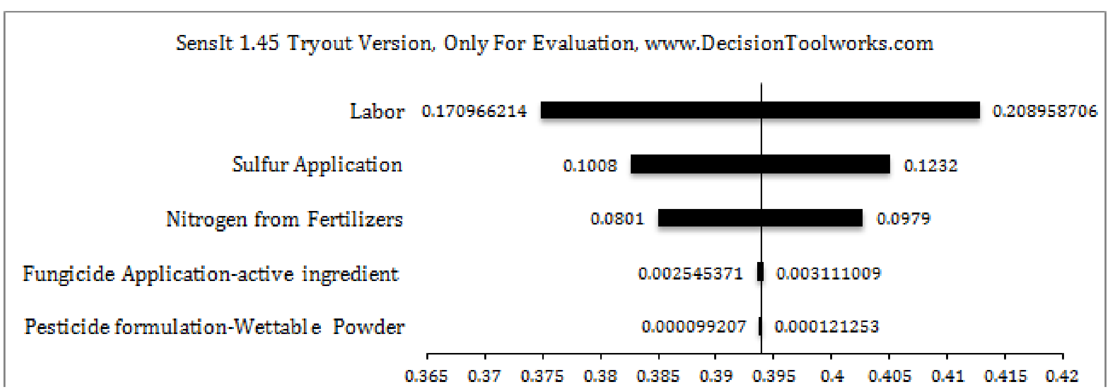


Figure 3: Organic CO2e Emissions Sensitivity Analysis



Conventional

Using the same input factors, results for the sensitivity analysis of conventional blueberries show that sulfur application is most sensitive variable for both energy intensity [Figure 4] and carbon dioxide equivalent emissions [Figure 5] and energy intensity**.** This is most likely a result of different amounts and types of fertilizers and fungicides that contain sulfur which are used to promote growth and production of blueberries. While the figures do indicate that sulfur applications are the most sensitive variable, it is important to note that for both outputs, labor is the second most sensitive. This implies that for both organic and conventional practices, the aggregate energy intensity and carbon dioxide equivalent emissions are highly contingent upon the type of labor work that is being practiced. Future research should focus on specific parameters and labor practices as different data for this specific variable may alter final results significantly.

Figure 4: Conventional Energy Sensitivity Analysis

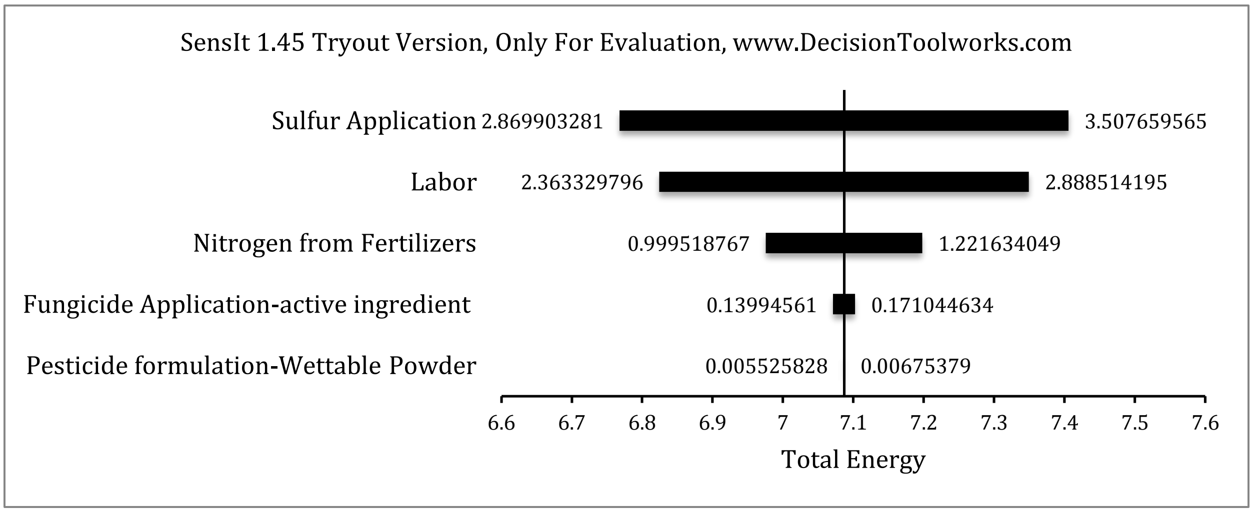
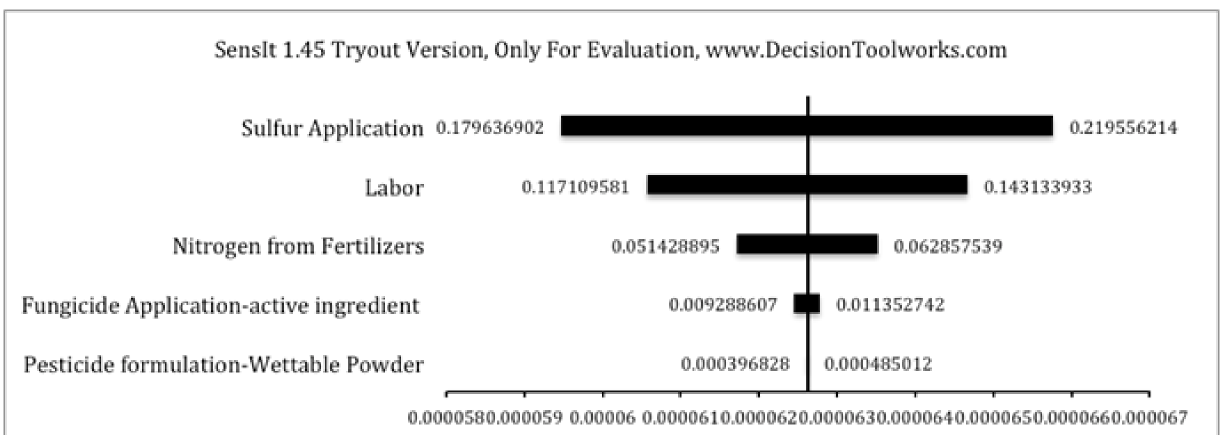


Figure 5: Conventional CO2e Emissions Sensitivity Analysis



Monte Carlo

In addition to evaluating the sensitivity of our inputs, we ran Monte Carlo analysis for energy and carbon dioxide equivalent emissions. After evaluating the same results, we were able to determine the mean values for the both organic and conventional growing methods. These results are displayed in Table 7. Note that these values do not match the base case values because Monte Carlo analysis was not simulated with all unit process inputs. After gathering the mean values, we calculated 95 confidence intervals for our mean values. The confidence intervals are displayed in Table 8. All Monte Carlo histogram simulations are attached in the Appendix.

Table 7: Mean Values from Monte Carlo Analysis

	Organic	Conventional
Energy	6.839077705 MJ/kg	7.087299018 MJ/kg
GHG	0.39412439 kgC02e/kg	0.397671655 kg CO2e/kg

Table 8: Confidence Intervals from Monte Carlo Analysis

	Organic	Conventional
Energy	(6.04-6.737) MJ/kg	(6.75-7.43) MJ/kg
GHG	(.375-.4133) kgC02e/kg	(.378-.4172) kg CO2e/kg

More Sensitivity Analysis - Yield and Transportation

There are two parameters which we decided were very crucial in determining energy intensities and carbon dioxide equivalent intensities which we did not know how to run on Excel, so instead we did some calculations. By performing a simple ratio calculation with the base case energy intensity results, we were able to determine the annual yield of organic blueberry production that had an energy intensity equivalent to conventional production. We found that if the annual yield per acre of organic production decreases by at least 1.57% of 6350.36kg, or 99.7kg, the energy intensity of organic blueberry production will be equivalent to that of conventional blueberry production. This is a crucial finding because it shows that yield is a very sensitive parameter in determining energy intensity. If there is error in the yield data by just 2%, the energy intensity of organic production may exceed that of conventional production. Similarly, we determined that if the yield of organic production was reduced by at least 12.8%, or 812.8kg, the carbon intensity of organic production would equal that of conventional production. This means that the energy and carbon intensity conclusions of our study are highly dependent on the yield statistics.

Furthermore, because we found a study that claimed that conventional blueberry production yield is actually 38% lower than organic yield [Parsons 2002], we decided to see how this affects energy and carbon intensities for 38% lower conventional yield while holding 6350.36kg fixed for organic. As expected, the energy intensity and CO2e intensity are much higher now [Table 9].

Table 9: Energy and CO2e Intensities Based on 38% Lower Conventional Yield

	Organic	Conventional	38% Lower Conventional Yield
Embodied Energy (MJ/kg)	31.10427755	31.60475627	50.97541333
Total Embodied Carbon (kgCO2e/kg)	0.722562185	0.828667981	1.33656126

In Venkat's study, it was assumed that organic inputs travelled 300km to get to the farm, while conventional inputs travelled a total of 1800km.The carbon intensities of transportation are 2.72 kgCO2e/km for organic production, while the carbon intensity of conventional production is 0.35 kgCO2e/km. Transportation carbon intensity of organic blueberry production is 7.7 times higher because organic requires larger quantities of fertilizers and organic matter to be transported, while conventional production consists of transporting small loads of highly concentrated chemical inputs. We wanted to see how the carbon intensities per kilogram of blueberry would change if organic transportation was doubled to 600km and conventional transportation was halved to 900km. Table 10 below demonstrates that the new kgCO2e/kg for conventional is 0.78, which is still not lower than the base case organic value of 0.72 kgCO2e/kg. However, the new kgCO2e/kg for organic is 0.85, which is higher than the base case conventional value of 0.83 kgCO2e/kg. This goes to show that transportation is also a very sensitive parameter in the determination of organic CO2e intensities.

Table 10: Transportation Sensitivity

	Carbon from Transport kgCO2e	Distance (km)	kgCO2e/km	New Distance (km)	New Carbon from Transport kg CO2e	New Total Carbon kg CO2e	New kgCO2e/kg
Conventional	626.02	1800	0.347788889	900	313.01	4949.33	0.7793779
Organic	815.76	300	2.7192	600	1631.52	5404.29	0.851021

IX. Summary of Results and Conclusion

Our analysis focused on a life cycle comparison of organic and conventional blueberry production. The results indicate that organic blueberry production is slightly less energy intensive and less CO2e intensive with 31.1 MJ/kg and 0.72 kgCO2e/kg, compared to 31.6 MJ/kg and 0.83 kgCO2e/kg for conventional blueberry production. Conventional production also involves the use of fertilizers and pesticides that are far more eco-toxic to air, water, and soil when application and leaching rates are considered. The nitrogen from conventional fertilizers also has a higher eutrophication potential than the nitrogen from organic fertilizers. Furthermore, because conventional has a higher CO2e intensity, it has a higher global warming potential. Cost effectiveness reveals that a 25% price premium for organic blueberries leads to a reduction in 1.1 kgCO2e over the course of one year and also leads to the use of much less environmentally harmful fertilizers and pesticides. Conclusions about energy intensity and CO2e intensity are highly sensitive to numerous parameters including labor, sulfur application, nitrogen from fertilizers, yield assumptions, and transportation. If yield for organic production is just 1.57% less than conventional yield, organic becomes as energy intensive as conventional. If yield for organic production is reduced by more than 12.8%, then organic production becomes more carbon intensive than conventional production. If transportation of organic inputs is doubled to 600km then carbon intensity becomes 0.85 kgCO2e/kg. The sensitivity of these parameters shows that organic is not by far more sustainable than conventional because slight input changes can greatly alter results. Furthermore, we must acknowledge the limited nature of life assessment as a tool of comparison. Our results do not imply that organic farming is superior to conventional farming, as other considerations and ripple effects must be taken into account. For example, if organic blueberry production does have a lower average yield, then more land would need to be utilized to produce the same quantity of food. This could imply the clear-cutting of forest and wildlife habitat, which would alter the environmental burden.

X. Limitations

A limitation to our current work is related to the data that we were able to access for use in our life cycle analysis. It was quite difficult for us to find data directly pertaining to a life cycle analysis of organic versus inorganic blueberries. There are plenty of LCA studies on organic and conventional food systems but we chose a specific fruit for which there may not be too much research on. The lack of data on the subject made performing analysis of blueberry life cycles somewhat difficult. Due to the lack of data, we based our analysis on limited sources. Thus, our data is not necessarily representative of the entirety of American blueberry production, but rather, is limited to a few studies.

One of the significant difficulties in performing our life cycle assessment survey was determining the most common pesticides, fertilizers, and herbicides used in current blueberry production. Blueberry farming practices can be very diverse and can involve many different chemical treatments, or no chemical treatments whatsoever. Given the high number of treatments available to farmers, variability is likely across production units, which contributes to uncertainty in our analysis. We had to select the pesticides and fertilizers which seemed to be most common and environmentally significant. We also selected pesticides and fertilizers whose eco-toxicities could be compared to their conventional or organic alternative. There is some inherent arbitrariness in the elimination of some fertilizers, pesticides, herbicides, and fungicides from our LCA. If we failed to include a highly toxic and common pesticide from our analysis, our environmental impact results could be very different.

Another difficulty in conducting our life cycle assessment was the availability of data. The primary studies that we used for reference are centered on organic and conventional blueberry production in the Pacific Northwest. Specifically, the majority of our data comes from studies conducted on blueberries grown in Southern California [Faber, Gaskell, et al. 2007]. This contributes to uncertainty through variability across locations. Variability across locations can stem from differences in soil quality and climates across the United States. This means our data is more representative of the needs of California blueberries given the soil quality and climate that exist in California. Other farms across the U.S.A. may have different needs for water or fertilizers depending on climate and soil quality. In addition, leaching rates are greatly influenced by soil type and likely vary across regions. For these reasons, our results could be skewed in some way and are not necessarily representative of the entire nation.

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XII. Appendix for Monte Carlo Histogram Simulations

Figure 6: Conventional Energy

Mean	7.087299018
St. Dev.	0.173715801
Mean St. Error	0.001737158
Minimum	6.543188247
First Quartile	6.965534207
Median	7.087871797
Third Quartile	7.207289135
Maximum	7.658446173
Skewness	-0.0132

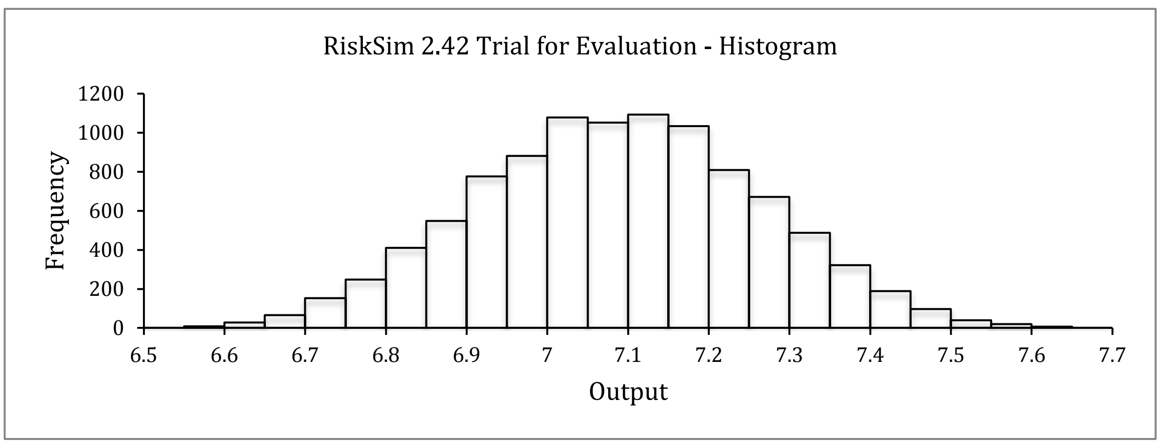

Figure 7: Conventional CO2e

Mean	0.397671655
St. Dev.	0.009970153
Mean St. Error	9.97015E-05
Minimum	0.363755995
First Quartile	0.390668731
Median	0.397570111
Third Quartile	0.404705805
Maximum	0.427104176
Skewness	0.0096

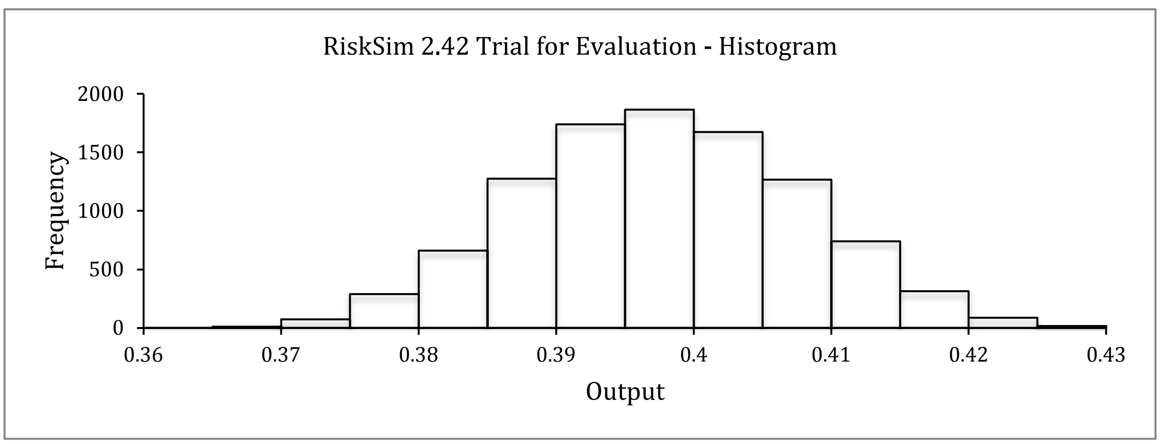

Figure 8: Organic Energy

Mean	6.839077705
St. Dev.	0.178147691
Mean St. Error	0.001781477
Minimum	6.268775524
First Quartile	6.713116457
Median	6.842388629
Third Quartile	6.964453221
Maximum	7.41052926
Skewness	-0.0310

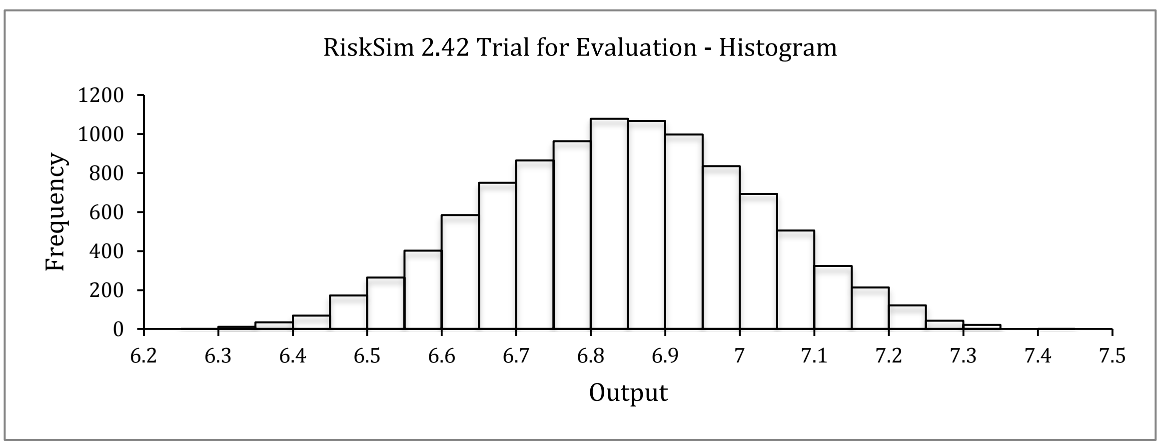

Figure 9: Organic CO2e

Mean	0.39412439
St. Dev.	0.009812388
Mean St. Error	9.81239E-05
Minimum	0.363197547
First Quartile	0.387359468
Median	0.394078484
Third Quartile	0.400997
Maximum	0.425925536
Skewness	-0.0001