DISSERTATION

EVALUATING THE SUSTAINABILITY OF AGRICULTURAL SYSTEMS USING LIFE CYCLE ASSESSMENT AND TECHNO-ECONOMIC ANALYSIS

Submitted by

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ABSTRACT

EVALUATING THE SUSTAINABILITY OF AGRICULTURAL SYSTEMS USING LIFE CYCLE ASSESSMENT AND TECHNO-ECONOMIC ANALYSIS

In a time of expansive population growth, our global resources have never been so strained; our contributions to a changing climate so significant. The International Panel on Climate Change recently addressed the need for focused effort toward reducing global resource depletion and greenhouse gas emissions (GHGs). As such, special attention has been given to some of the largest GHG emitting sectors in the world: energy, industry, and agriculture. This work focuses on using sustainability analysis to further understand agricultural processes and products, both novel and emerging. To quantify the environmental component of sustainability, life cycle assessment (LCA) is used because it is a well-established method for evaluating processes and products with respect to emissions. Similarly, techno-economic analysis (TEA) is used to understand the economic viability of various processes and products. In harmony, these assessments are used to evaluate the sustainable performance of various agricultural processes and products by identifying pathways to reduce environmental impact while concurrently increasing economic viability. Results enable targeted research to be highlighted that can advance early-stage development toward a sustainable adoption. The dissertation proposal is divided into three topics all with a common theme: Using LCA and TEA to assess the sustainability of, and advance, agricultural systems.

A drought tolerant crop currently grown in India, guar, was investigated to understand relative environmental impact and economic viability in the American Southwest compared to existing crops. Guar is cultivated as a source of guar gum, used primarily in hydraulic fracking fluid for shale oil and gas recovery, with demand currently met through importation. Therefore, a feasibility analysis was performed for a domestic guar supply in Arizona and New Mexico using LCA and TEA. The integrated assessment

provided insight on environmental and economic performance of guar for comparison to existing crops. Results indicate that environmentally, guar has lower GHGs than many crops currently cultivated in the American Southwest. Economically, guar gum can be produced for less than the five-year average U.S. import price, with minimizing or eliminating irrigation identified as a critical area for further research. A best case scenario and sensitivity analysis are also investigated using LCA and TEA to evaluate early-stage development of adopting guar in the American Southwest.

LCA is also a valuable assessment tool for emerging agricultural systems. A detailed LCA was performed for a first-of-its-kind study investigating the GHGs of commercial indoor cannabis cultivation. Since legalization, the cannabis industry has seen substantial growth with many products being cultivated inside industrialized warehouses. An engineering process model was built to track material and energy requirements of a typical indoor cannabis facility which was then translated to GHGs using LCA methodology. Results of a U.S.-wide analysis indicate that indoor cannabis production leads to substantial GHGs regardless of where it is cultivated, with regions such as the Mountain West and Midwestern United States being much more GHG intensive than East or West Coasts. Individual processes that lead to the majority of GHGs are heating, ventilation, and air conditioning (HVAC), high intensity grow lights and the addition of carbon dioxide for increased plant growth rates. Results of this work have informed the industry, consumers, and policymakers of the environmental impact from this practice while providing insight on ways to reduce GHG emissions.

Despite LCA and TEA being proven methodologies for assessing novel, emerging and established processes and products, limitations do exist. Particularly, in the context of agriculture, LCA does not traditionally account for water use outside of the emissions associated with procurement and use. In the American Southwest specifically, it is critical to understand water use and associated environmental impact to make informed decisions regarding ecosystem and societal sustainability. Recently, the development of an advanced LCA method, water scarcity footprint (WSF), has enhanced that ability to understand spatial and temporal considerations of freshwater consumption. However, this method is actively emerging and therefore limitations exist, particularly for arid regions where water demand is typically higher than the amount of water available. A novel method was proposed that can improve resolution and decision-making capabilities for freshwater environmental impact when evaluating arid regions. Results include method comparisons that highlight the improved resolution between the developed method and the traditional WSF method. Furthermore, a case study shows variation of the two methods when applied to alfalfa production in the American Southwest that reveals the severity of drought in the region. The proposed method enables improved resolution when considering spatial and temporal freshwater use in arid regions which enhances decision-making capabilities for product development.

Throughout this work, traditional and advanced sustainability metrics, LCA, TEA and WSF, were used to understanding the environmental impact and economic viability of various agricultural-related products. Results from these assessments, from novel and existing technology investigation, provide quantifiable results for holistic comparisons and internal process improvement. These results can serve as decision-making tools during the research and development and commercialization stages, all leading toward providing a more sustainable future.

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CHAPTER 1: INTRODUCTION

In the face of a changing climate, there is a great need to understand how to improve environmental and economic sustainability. The Intergovernmental Panel on Climate Change (IPCC) special report highlights the need for reducing greenhouse gas emissions (GHGs) in sectors such as energy, industry, and agriculture[1]. The Agriculture, Forestry and Other Land Use category within the report represents 24% of the world's total GHGs with agriculture accounting for most of those emissions. There is great urgency to understand, evaluate, and improve agricultural processes toward reducing GHGs. With the complexities of agricultural processes, however, these GHG reduction efforts cannot be achieved without considering economic implications throughout the supply chain. Life cycle assessment (LCA) and techno-economic analysis (TEA) are two well-established methodologies that exist to quantify environmental impact and economic viability[2–4]. LCA and TEA can be used for emerging technologies to help inform environmental- and economic-related questions during research and development (R&D) or be applied to existing commercialized technologies for continual improvement. Combining LCA and TEA assessments when evaluating agricultural supply chains can enable a thorough understanding of the environmental impact and economics allowing for further optimization. The coupled analyses can also allow for trade-off evaluation between environmental impact and economics.

LCA and TEA are built around material and energy inventory which details all inputs required to develop a new product or process. The material and energy inventory serves as the foundation for both the LCA and TEA. For LCA, evaluations are performed for the full life cycle including production, distribution, use and disposal, specifically through life cycle inventory provided by robust databases. These emissions are aggregated and interpreted through methods provided by the Environmental Protection Agency (EPA) for comparison to other products and processes[5]. For TEA, the material and energy inventory is used to determine capital and operational expenses. Combining these expenses with other economic indicators such as an internal rate of return, loan structure, deprecation and taxes, a technology evaluation can be performed to understand economic viability in comparison to existing products and processes. These assessments can be used concurrently in early stages of product development for understanding of trade-offs and stage-gate decision making.

Using LCA and TEA to evaluate environmental and economic performance of early-stage product development can save time and money. Understanding how processes and products will systematically perform, both economically and environmentally, at a commercial scale is valuable during R&D. Results of LCA and TEA can evaluate whether potential products will be environmentally or economically competitive with existing market competitors. In situations where early-stage LCA and TEA yield non-competitive results, data feedback can assist R&D toward minimizing emissions and cost prior to commercialization. Specifically, LCA can identify primary sources of emissions within the system, allowing future research to focus on specific areas that will reduce total emissions. Similarly, results from TEA can identify material inputs or processes within a system and guide R&D to focus efforts toward minimizing total costs of the product or process. While LCA and TEA are often applied in an industrial or manufacturing setting, they can also be useful in other fields such as agriculture.

In this work, three chapters are presented that use LCA and TEA methods to evaluate the environmental impact and economic performance of various agricultural products and processes. The three research phases included in this work are: 1) A feasibility analysis of cultivating gaur and producing guar gum in the American Southwest using LCA and TEA methods, 2) a geospatially resolved evaluation of the GHGs from commercial indoor cannabis production across the United States, and 3) Development of advanced LCA methods that enhance the resolution of freshwater impact assessments in arid regions. The following three chapters provide a detailed account of each research phase through background information, methods, and major findings of each phase of work. The combined research phases identified and evaluated research gaps for an improved understanding of sustainability within agricultural systems.

CHAPTER 2: SUSTAINABILITY EVALUATION OF GUAR THROUGH LCA AND TEA METHODS[a]

2.1. Background

The American Southwest is seeing increased agricultural drought due to effects of a growing population and changing climate. Access to sustainable and reliable fresh water supply presents risk to both urban and rural communities. Within rural communities, farming represents one of the largest consumers of fresh water. These farmers face risk of crop loss and reduced revenue as the difference between fresh water supply and demand increases. Introducing low water using, drought-tolerant crops that yield high-value products can mitigate this risk for farmers. These crops have the potential to decrease the farmer's dependence upon fresh water, while providing a steady source of revenue.

One notable, drought tolerant crop is guar (*Cyamopsis tetragonoloba* L.). Guar is a legume, commonly imported to the United States from India, which is known for its resilience in arid environments and nitrogen-fixing qualities[6–8]. Guar produces galactomannans within the endosperm of the seed which provide thickening and stabilizing properties when mixed in fluids. The most common product of guar galactomannans is guar gum, which is used in a wide range of products including paper, cosmetics, paints, detergents and foods (ketchup, jam, yogurt, salad dressing and milk, to name a few) [6,9,10]. In addition to these products, within the past decade, guar imports in the United States increased due to its use in hydraulic fracking fluid for shale oil and gas recovery[6–8]. The high demand for guar gum is being met primarily through import, however, there exists a need for a domestic supply of guar gum due to market instability[11,12]. Although several publications highlight the ability to cultivate guar in the United

[a] This chapter was published as a peer-reviewed journal article: Hailey M. Summers, Evan Sproul, Clark Seavert, Sangu Angadi, Joram Robbs, Sita Khanal, Paul Gutierrez, Trent Teegerstrom, Daniel A. Zuniga Vazquez, Neng Fan, Jason C. Quinn, Economic and environmental analyses of incorporating guar into the American southwest, Agricultural Systems, Volume 191, 2021, 103146, ISSN 0308-521X, https://doi.org/10.1016/j.agsy.2021.103146.

States, minimal information can be found regarding the economic viability or environmental impact of domestically cultivating and processing guar into guar gum[13–15].

Previous work has illustrated that guar is a low-emission crop, nitrogen-fixing and drought tolerant[6–8]. Guar has not only been recognized for its ability to withstand long periods between watering, but its overall limited irrigation requirements are also desirable [13]. Despite these positive attributes of guar, very few studies have focused on the full characterization of the crop's sustainable performance through economic and environmental analyses. A comprehensive sustainability analysis of guar was published by Gresta et al. (2014) in which economic and environmental analyses of cultivating guar in the Mediterranean were completed. Although this publication is thorough, it focuses primarily on cultivation and does not include transportation of the guar seed or downstream processing of guar to produce guar gum. Additionally, Gresta et al. (2014) used geographically relevant data for the Mediterranean making it difficult to compare their results to other crops currently grown in the Southwest. To the authors' knowledge, no literature exists that is focused on the economic and environmental feasibility of the conversion process from guar to guar gum. Furthermore, no literature exists that applies economic and environmental impact methodology to cultivating and processing guar to guar gum within the United States.

Based on these shortcomings, the presented work has generated three separate novel contributions: 1) A detailed engineering process model for cultivating, transporting, and processing guar into guar gum in the southwestern United States. 2) Cradle-to-gate techno-economic analysis (TEA) and life cycle assessment (LCA) based upon the engineering process model. 3) Integration of U.S.-based field experimental data to understand economic and environmental implications of varying irrigation amounts and associated yield. Results are presented on system-wide performance and include sensitivity and scenario analyses to provide recommendations for further investigation.

2.2. Methods

The methods are organized in sections outlining: 1) development of detailed engineering process models that accurately captured the materials and energy needed to cultivate guar and process it into guar gum, 2) coupled TEA and LCA evaluating the economic and environmental feasibility of producing guar gum in the American Southwest and 3) scenario and sensitivity analyses to understand economic and environmental impact from varying irrigation amount.

2.2.1. Engineering Process Model Development

The engineering process model is a high-resolution process model that captured the materials and energy required to cultivate guar and process it into guar gum. The system boundary, shown in Figure 2.1, includes the processes of cultivating guar crop, transporting harvested guar seed from the field to a processing facility and the processing facility where the guar seed is converted to guar gum. All processes and analyses were developed in Microsoft Excel using Visual Basic for Applications to execute various analyses, including the economic, environmental, and sensitivity analyses described in subsequent sections.

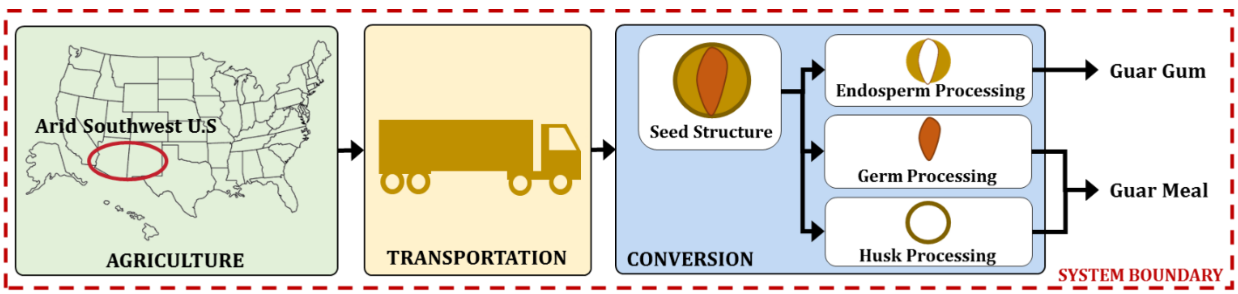

Figure 2.1*: Model framework of cultivating guar and processing it into guar gum and guar meal.*

2.2.1.1. Agricultural Process Model

The agricultural process model was developed to understand the requirements of cultivating guar in the arid states of Arizona and New Mexico. Detailed inventory was tracked to capture the material and energy required throughout the guar cultivation processes of land preparation, seeding, growing, and harvesting. Data for various guar processes and inputs were obtained via field experimental trials, interviews with guar producers and supplemented with literature values when necessary. The baseline agricultural analysis was developed by averaging specific inputs and outputs from field trials data, presented in Table 2.1, and all field trials occurred in a growing season that received 0.34 meters of rainfall.

The agricultural process model includes material inventories for guar seed, water for irrigation, fertilizers, herbicides, and insecticides required for the crop. It also includes energy inventories of electricity and diesel used in farm equipment and irrigation pumping. The agricultural process was modeled to represent a typical farm size of 600 hectares in the region, an average between Arizona and New Mexico[16,17]. The baseline analysis of this study investigates the feasibility of adopting 15% (90 hectares) for guar cultivation from existing agricultural land allocated to cotton, wheat, sorghum, alfalfa, hay, and corn cultivation (see Appendix, Table A.1 for full farm layout).

Table 2.1: *Baseline inputs for the agricultural process model based on average field trial data.*

	Baseline Agricultural Inputs		
Land Prep	Moldboard Plow + Drag	1	pass/ha
Seeding	Drill	8.98	kg/ha
	Drill	1	pass/ha
Irrigation	Sprinkler	0.24	meters
Fertilizer	N-based	6.74	kg/ha
	P-based	22.5	kg/ha
	Tractor + Sidedresser	1	pass/ha
Herbicide	Treflan	1.75	liter/ha
	Prowl H2O	0.94	liter/ha
	Tractor + Boomsprayer	2	pass/ha
Insecticide	Leverage® 360	0.30	liter/ha
	Tractor + Boomsprayer	1	pass/ha
Harvest	Custom Combine	1	pass/ha
Yield	Guar Seed	1,024	kg/ha

The baseline model included land preparation steps for guar as rotary tilling and ploughing. Before planting, recommended fertilizer levels based on soil test results, in the form of liquid fertilizer mixture of nitrogen and phosphorous, were applied using a tractor mounted sprayer and incorporated into soil. The pre-plant herbicides Treflan HFP (α, α, α-trifluoro-2, 6-dinitroN, N-dipropyl-p-toluidine; Dow AgroSciences, Indianapolis, IN) at 1.75 L ha^{-1} and Prowl H2O (S-metolachlor; BASF, Research Triangle, NC) at 0.94 Kg a.i. ha^{-1} were incorporated into soil for weed management. Leaf minor infestation was controlled using Leverage® 360 insecticide (Bayer Crop Science, Research Triangle, NC). Irrigation was applied using sprinkler or center pivot. A total of 0.24 meters of irrigation was applied at various stages of plant growth. Guar was harvested using a custom combine. The total harvested guar seed yield and residual biomass was modeled as 1,024 kilograms per hectare and the moisture content was 13.5% by weight[18]. This data was supplemented by literature as it was not included in the field trial data.

2.2.1.2. Transportation Logistics Process Model

The transportation process model included transporting the harvested guar seed and residual biomass from the farms to a facility for processing. Transportation distances were calculated by a previously developed optimization model using modified inputs consistent with data from this study[19]. The optimization model from Zuniga Vazquez et al. (2021) determined the ideal processing facility location with respect to nearby farms that could feasibly adopt guar. The processing facilities proximity to resources such as roadway, railway, and utilities (water, electricity, and natural gas supply) were also considered. The optimization model was performed on Dona Ana County, New Mexico which yielded an optimized transportation distance of 38.9 km. This distance and associated costs were applied to all farms consistently. Although the transportation distance was based on expected guar farm locations and processing facility in New Mexico, it was found to be similar to transportation distances for more established products such as corn ethanol in both Iowa and Ohio[20]. A map of the ideal facility location and surrounding farmland suitable for guar production in Dona Ana County, NM is provided in the Appendix (Figure A.1).

To meet the throughput demand of the guar seed processing facility (discussed in detail in 2.2.1.3 Downstream Processing Systems Model), a total of 13 trucks were needed to transport biomass for eight hours per day during the harvest season of November and December. The seeds were then stored on-site for continual, year-round feed into the processing facility. Payload, road speed, drive time, and loading and unloading time were considered in determining the number of trucks. Detailed transportation inputs is provided in the Appendix (Table A.3).

2.2.1.3. Downstream Processing Systems Model

The guar processing model represents a facility that receives guar seed and converts it to guar gum. The downstream processing facility and design were largely based upon communication with the only United States-based guar processing facility, Guar Resources, located in Brownfield, TX with supplemental data obtained from literature and patents[21–23]. For reference, a detailed process flow diagram of the process is outlined in the Appendix (Figure A.2). The model was designed around a representative facility with a 30-year lifetime, operating 350 days per year, capable of processing 22,680 tonnes (50 million lbs.) of guar seeds per year. To meet this throughput by modeling representative 600-hectare farms, a total of 245 farms (1% of total farms in Arizona and New Mexico combined) were modeled. The processing facility accounts for storing the necessary throughput of guar seed, harvested in November and December, for year-round processing.

The processing of guar seed to guar gum began by modeling the removal of residual biomass from the field. The harvested biomass passed through a shaker table that removed 9% of plant material containing mostly stock. Next, the endosperm was extracted through several steps, as outlined below, leaving what is referred to as "splits." Splits are the two halves of the seed portion containing only endosperm (32.5% of the seed by mass, refer to **Figure 2.1** for seed structure layout) and are the source for guar gum. Splits were obtained by first milling the seeds in half, allowing them to fracture along the germ line. The germ (~40% of the guar seed by mass) was separated, cleaned and packaged and modeled as a high-protein co-product for animal feed, similar to cotton, soybean and canola meals[24]. Second, the halves (endosperm and hull) went through heat treatment and hydration processes where the moisture content was raised to 30% by mass (from 13.5%) using high-quality steam. Then, the halves were de-hulled (~27.5% of the seed by mass) and since the hull contains some protein as well, it was also separated, cleaned and hopper-fed into super sacks in combination with the germ. Both the germ and hull co-product streams were modeled as one combined animal feed co-product. The portion that remained, splits, were passed to the conversion process that starts with a hydration bath to increase the moisture content to 45% by mass (35-55% is an acceptable range[23]). Increasing the moisture content is critical to ensure quality of the final guar gum, namely consistency in particle shape and size. The splits then went through a series of flakers before being dried via a spray dryer. Last, the dried powder is ground to create uniform, finely powdered guar gum modeled with a moisture content of 11% by mass[25]. The final particle size of the guar gum is set by its end use, course powder is required for food applications whereas a fine powder is required for oil and gas application. Results presented in this work represent modeling efforts for guar gum used in oil and gas applications.

Cumulatively, these operations make up the downstream processing facility. A mass balance was performed across processes to determine associated flowrates. Equipment was sized based on flow rates and corresponding manufacturer specification data was used to determine associated economics and energy requirements. Facility staff and labor estimates were scaled based on flowrates of a similar economic analysis[26]. Specific modeling inputs for downstream processing are presented in the Appendix (Table A.4).

2.2.2. Economic Analysis

The economic analysis is founded on the material and energy results from the engineering process model described in section 2.2.1 Engineering Process Model Development. The economics associated with agriculture, transportation and processing were aggregated into a combined, system-level TEA. To combine the economics of the three processes, the agricultural economics first determined the breakeven price of harvested guar seed necessary to recover the cost of growing the crop. The breakeven price of the seed was combined with transportation costs and processing costs to determine a minimum selling price (MSP) of guar gum ($ kg-guar gum^{-1}) such that expenses of the entire cradle-to-gate system were recovered over a 30-year lifetime. Details for process level economics are provided in subsequent sections and system-level TEA outputs are provided in 3.1 Economic Analysis.

2.2.2.1. Cultivation Economics

At A full-farm analysis was established to evaluate the economic impact of adopting 15% guar acreage on the farm (crop allocation of the full farm provided in Table A.1). A full farm was considered to account for equipment sharing across multiple crops on the farm. This sharing reduces the overall equipment costs allocated to guar (see Table A.7 and Table A.8 for full farm equipment accounting). Results from the analysis provide the breakeven selling price of guar seed necessary to recover the associated costs of growing guar annually. The cultivation processes accounted for included land preparation, seeding, crop management and harvesting. The necessary material and energy inputs for these processes include water, fertilizer, herbicides, insecticides, electricity, and diesel. Fixed costs for farm equipment replacement were accounted for along with fuel, repairs, maintenance, and labor. Fixed machinery costs, repairs, and maintenance costs were attributed to the portion of the farm cultivating guar crop, 15% of a representative farm. Additionally, an interest rate of 8% was applied to a six-month loan for both the harvest and out-of-pocket production costs, but the breakeven analysis did not consider profit to the farmer. An annual guar crop budget for the baseline scenario can be found in the Appendix (Table A5). The farm-level economic analysis solves for the breakeven price needed for guar seed to recover the costs associated with cultivating guar on the farm. The breakeven price of guar seed represents the purchase price to the downstream processing facility, modeled as an operating expense.

2.2.2.2. Processing Economics

The economics for the downstream processing facility include the guar seed breakeven price, from 2.2.1.1 Agricultural Process Model, transportation costs as operational expenses, and all costs associated with the processing of guar seeds to guar gum including co-product revenue for animal feed. Therefore, the integrated economic analysis represents one cradle-to-gate TEA that determined the MSP of guar gum needed for the processing facility to yield a net present value of zero after the full operating lifetime. This MSP represents the price of guar gum necessary to recover costs associated with agriculture, transportation, and downstream processing.

The integrated economic analysis was evaluated using TEA methodology with assumptions from the standard reference of "N^{th}" plant design outlined in previous studies performed by the National Renewable Energy Laboratory and Pacific Northwest Laboratories[4,27,28]. The "Nth" plant assumptions represent technologies that are assumed to be well established, as opposed to a first-of-a-kind analysis that would need to account for additional costs such as longer start up times, special permitting, and high contingency percentages. The guar TEA evaluates a 30-year processing facility, 10-year loan at 60% debt with an 8% interest rate, 10% internal rate of return and a 7-year Modified Accelerated Cost Recovery System (MACRS) depreciation schedule[4,27,28]. The construction period was modeled at 20 months which is representative of similar dry milling processes such as dry grind corn ethanol[29,30]. Capital and operational costs were determined from the engineering process model.

Capital costs include the necessary land, infrastructure, and equipment to process guar gum at scale. Equipment size and capital pricing were based on material flow rates from the engineering process model. Installed costs, above capital, were determined via scaling equipment sizes with installation factors and characteristic scaling exponents[31]. Total installed costs, above installed costs, were determined by applying indirect and contingency costs[32]. Variable and fixed operating costs such as electricity, natural gas, and labor, were determined for the southwestern United States specifically. Model assumptions consistent across all processes within the facility include the following costs: electricity purchased at $\$0.059\ \text{kWh}^{-1}$ [33], water at $\$0.13\ \text{tonne}^{-1}$ [34], and natural gas at $\$5.64\ \text{MCF}^{-1}$ [35]. An operational revenue stream was applied for the co-product of guar meal (animal feed) at $0.31 per kg ($0.14 per lb)[36]. Further detailed capital, fixed, and variable operating costs are provided in Appendix A (Table A.6).

2.2.3. Environmental Analysis

Similar to the economic analysis, an environmental analysis was performed using material and energy results from the process model. Life cycle assessment methodology was used to assess environmental performance of the cradle-to-gate guar gum process and to identify areas for improvement within individual processes. Methodology applied to the process model is consistent with LCA framework outlined by the International Organization for Standardization[2]. The system boundary for the environmental analysis follows that of the economics and includes agriculture, transportation, and downstream processing.

Material and energy inputs within the system boundary, outlined in section 2.1 Engineering Process Model Development, were used as the foundation for the LCA. The material and energy inputs were coupled with associated life cycle inventories (LCI) representative of cradle-to-gate emissions. LCI were primarily obtained from ecoinvent v3.4 using cutoff methods, and supplemented from U.S. Life Cycle Inventory when unavailable[37,38] (see Appendix Figure A.8 for LCI). The modeled emissions were evaluated at midpoint categories using the U.S. Environmental Protection Agency's recommended Tool for Reduction and Assessment of Chemicals and Other Environmental Impacts (TRACI v2.1)[5].

2.2.3.1. Agricultural Environmental Analysis

Material inputs specific to the agricultural process refer to inputs such as water, fertilizer, herbicides and insecticides whereas energy inputs refer to the electricity or diesel required to supply the material inputs for a particular process (i.e. diesel combusted in a tractor to apply fertilizer). The material inputs were tracked through processes of land preparation, seeding, fertilizing, irrigating, applying herbicide and insecticides and harvesting, outlined by the engineering process model. The corresponding environmental analysis for these material inputs was developed using supporting documentation specifically for agricultural production systems[39]. Detailed process accounting was built around Tables A.9 – A.11 of Chapter 15, Life Cycle Inventories of Agricultural Production Systems[39], allowing for appropriate inputs to be adjusted for guar specific practices. For example, the material and energy data from irrigation sub-processes (on a hectare basis, see Table A.11 in Nemecek and Kägi, 2007) were linearly scaled by a ratio of guar irrigation amount to default ecoinvent v3.4 irrigation amount. This linear scaling ensures that the environmental impact is associated with the guar irrigation amount and not scaled on a hectare basis with a fixed irrigation amount. Similar methodology was applied to all agricultural processes that required adjustment for guar-specific inputs. Field emissions were omitted due to a lack of data, both from existing LCI database and field trials data.

2.2.3.2 Processing Environmental Analysis

The downstream processing facility converts guar to guar gum primarily by dry mechanical processes requiring no chemicals. The only material input needed at various stages is water, typically in the form of steam. Therefore, the downstream processing facility environmental impact stems from electricity and natural gas required to operate various equipment within the extraction and conversion processes outlined in the Appendix (Figure A.2). Electricity and natural gas use were determined from the material and energy balance performed across the process model and were overlaid with LCI. Resulting emissions were aggregated across the processing facility and are presented for water, electricity, and natural gas impact on a kg-guar gum basis.

2.2.3.3 Co-product Displacement and Allocation

Within the system boundary, the primary product of guar gum and co-product of guar meal are generated. Guar meal was modeled as displacing emissions associated with the production of soybean meal and was applied to the cradle-to-gate cumulative emissions. Soybean meal emissions were obtained from modeling the processes of soybean cultivation and downstream processing for oil extraction, which generates a co-product of soybean hull for animal feed[38]. A mass allocation for soybean hull, 80% of total processing throughput, was applied to the soybean cultivation emissions and added to the soybean processing emissions which were already allocated to the soybean meal product portion. The combined emissions were modeled as displacement credit to the cradle-to-gate, guar gum process. See Figure A.4 of Appendix A for allocation process flow diagram and supporting equations. Results are presented for both guar gum and guar meal and are presented on a kg-guar gum basis.

2.2.4 Scenario and Sensitivity Analyses

Scenario and sensitivity analyses were performed on the process model to evaluate performance with respect to economics and environmental impact. Scenario analyses were built into the process model based on field trial data. Previous literature highlighted guar's sensitivity to irrigation, therefore the field trials data were used to focus on economic and environmental performance of ranging irrigation amount. Impact on economic and environmental performance was evaluated for four irrigation amounts, eight replicates each, and results are shown using the mean and standard deviation of data set. The baseline scenario represents averages of the field trials data. The baseline model inputs are consistent with previously outlined sections, with specifics provided in **Table 2.1**. Outputs for both the individual and baseline field trails are presented in the results. Furthermore, a best case scenario was investigated to understand economic and environmental performance of potentially attainable scenario based upon operating practices with data provided by commercial guar farmers.

A sensitivity analysis was used to investigate the model outputs response to all individual input parameter changes, not just irrigation. A sensitivity of ±20%, with respect to each individual variable, was performed at both the economic and environmental impact level. Inherently, some input parameters cannot physically be ±20%, however, results of the sensitivity analysis are intended to highlight which variables are sensitive to change and therefore warrant focused investigation. Results are used in combination with scenario analyses to identify critical areas for further research and development with respect to economic and environmental performance.

2.3. Results

2.3.1 Economic Analysis

Economic results, presented in **Figure 2.2**, represent the baseline MSP of guar gum necessary to recover costs of production for the lifetime of the processing facility (as outlined in 2.2.2 Economic Analysis). Total costs ($2.12 per kg-guar gum) were offset with animal feed as a co-product credit ($0.68 per kg-guar gum) to result in a total MSP of $1.44 per kg-guar gum. The MSP is compared to the five-year average U.S. import price for guar gum of $0.99 per kg-guar gum. Although the total MSP resulting from the baseline scenario is greater than the five-year average U.S. import price for guar gum, identifying the largest contributions of the process can aid in further reducing the cradle-to-gate MSP.

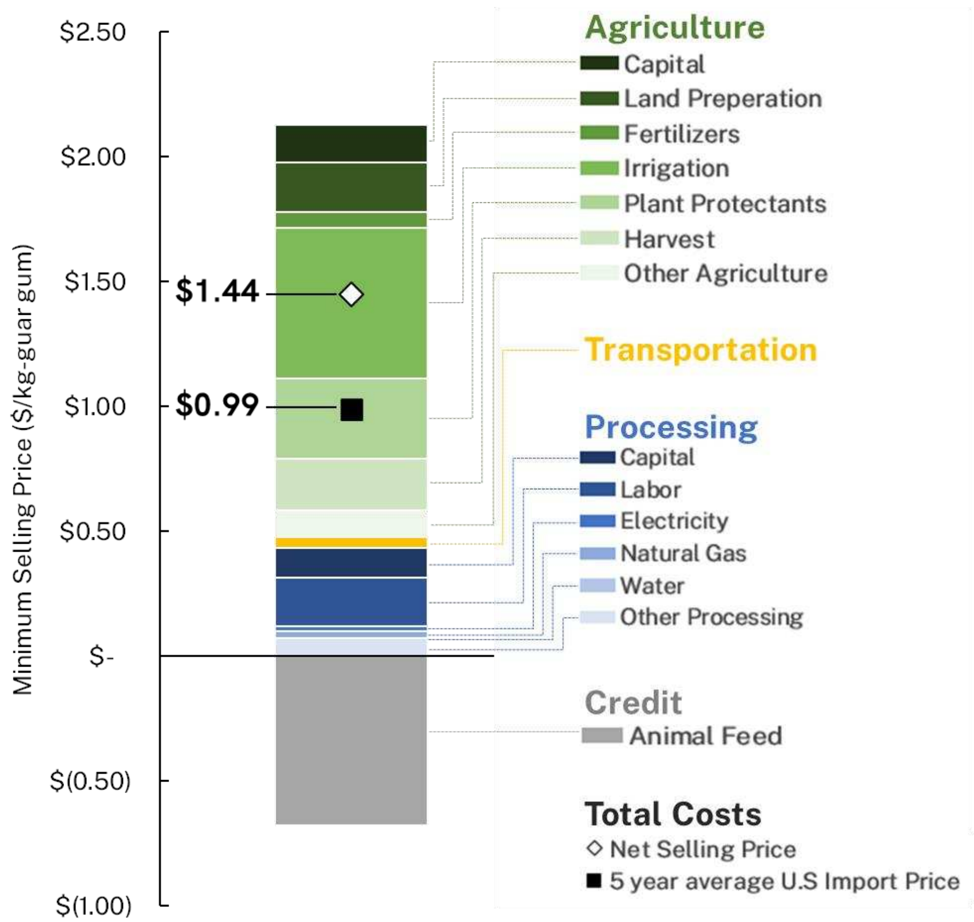

Figure 2.2: *Minimum selling price ($/kg-guar gum) to produce guar gum in the southwestern United States for the baseline model. Results include agriculture (green), transportation (yellow), downstream processing (blue), and animal feed co-product credit (grey).*

Total agriculture costs account for $1.65 per kg-guar, or 78% of the total costs. The largest contributors to agriculture costs were irrigation ($0.60 per kg-guar gum), plant protectants and associated application ($0.32 per kg-guar gum), and harvest ($0.21 per kg-guar gum). Transportation only contributes $0.04 per kg-guar gum (2% of total costs) due to the optimized location of the processing facility, and therefore minimized transportation distance, with respect to the guar farms. The downstream processing facility accounts for $0.43 per kg-guar gum, 20% of the total costs, with the largest contributors being labor ($0.20 per kg-guar gum), fixed capital and loan ($0.12 per kg-guar gum) and other processing ($0.07 per kg-guar gum). For the processing facility, “other processing” consists of equipment maintenance, insurance, tax, and land. The remaining contributions to processing costs include electricity ($0.02 per kg-guar gum) and natural gas ($0.03 per kg-guar gum). Of these contributions, it is recommended that future research focus on minimizing costs associated with cultivating guar, specifically the processes of irrigation, plant protectants (materials and application process), and harvest, as these inputs and processes account for the majority of costs.

2.3.1.1 Sensitivity Analysis

A sensitivity analysis was performed on all individual modeling input parameters, ranging them ±20%, to gauge economic response with respect to MSP. Results of the top ten most sensitive modeling parameters are shown in **Figure 2.3**. Refer to the Appendix A (Figure A.3) for a comprehensive list of the sensitivity analysis results. Harvest yield and harvest area (hectares harvested) are among the top ten as there is a direct correlation between guar seed yield and guar gum, which is the functional unit of the MSP. Current research activities are focused on adopting higher yielding guar cultivars and developing management practices to increase guar productivity, which in turn will significantly reduce MSP of guar gum. The co-product revenue value for animal feed is sensitive as it recovered 32% of the baseline total costs.

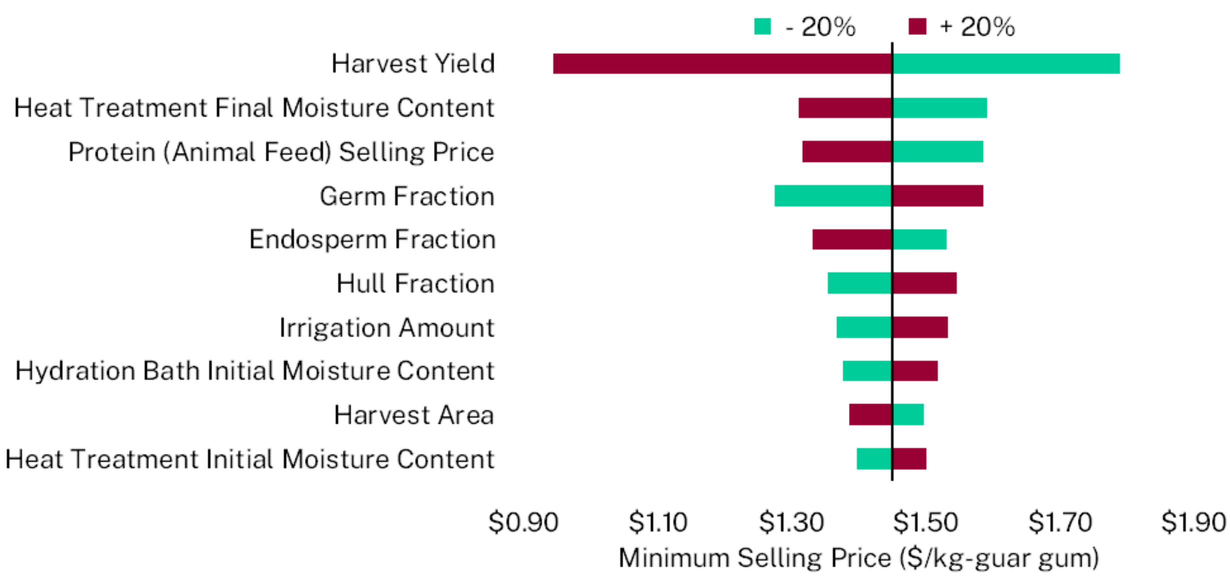

Figure 2.3: *The ten most sensitive modeling parameters, with respect to MSP of guar gum, for the baseline scenario.*

It is interesting to note that several modeling parameters relevant to downstream processing (heat treatment, final moisture content, germ fraction, endosperm fraction, hull fraction, hydration bath initial moisture content and heat treatment final moisture content) show high sensitivity to MSP, yet downstream processing only accounts for 20% of the total costs in the baseline scenario. Conversely, only three parameters (harvest yield, harvest area and irrigation amount) stem from agriculture costs, which account for 78% of the baseline scenario costs. Harvest yield and harvest area, as mentioned previously, directly impact the functional unit and irrigation amount is the largest individual contributor to the MSP (29% of total costs), so it is reasonable that these parameters are sensitive. The remaining agricultural parameters are shown to be less sensitive due to the complexity and resolution of the agriculture process model. The agricultural categories labeled equipment, fertilizers, and plant protectants of **Figure 2.2** include approximately 1,000 parameters that only contribute 49% (excluding the 29% from irrigation) of the total costs. Despite the significant contribution to MSP, it is not surprising that ranging these parameters individually has minimal effect on total MSP. The downstream processing facility, when compared to agricultural processes, is relatively simple and includes only approximately 100 parameters. Therefore, it is more likely that one of these parameters would be economically sensitive to an input change of ±20% than those from the agricultural process model.

Understanding these highly sensitive parameters can help inform further research. These parameters show that slight modifications to input parameters could greatly impact the MSP. These results, however, do not account for larger, whole process-level changes that might also increase or lower MSP. Process level changes to the guar process model are further developed in the discussion.

2.3.1.2 Comparison to Existing Literature

Comparison of the guar gum MSP was limited due to a lack of available resources. The only peer-reviewed guar economic comparison available was to agricultural costs from Gresta et al. (2014), in which production costs of guar crop were $2,897 per hectare per year and $3,315 per hectare per year for the two farms analyzed. Converting units of **Figure 2.2**, the agriculture costs of $1.65 per kg guar-gum compares at $503.62 per hectare per year (using baseline yield of 1,024 kg guar seed per hectare and a

30% processing efficiency of guar seed to guar gum). This discrepancy in agricultural costs can be largely attributed to differences modeling scenarios, primarily fertilizer, irrigation, and seeding amounts.

Gresta et al. (2014) applied 260 kg per hectare of nitrogen-based fertilizer to both of their case studies whereas the baseline input here was 6.7 kg per hectare. Similarly, their work shows an applied 150 and 200 kg per hectare of phosphorous-based fertilizer to their two case studies and the baseline input here was 22.5 kg per hectare. The fertilization rates reported from Gresta et al. (2014) are higher than reported literature values for guar ranging from 20-60 kg per hectare for both N- and P-based fertilizers, but are similar to fertilization rates of wheat and corn[8,12,40]. The reason for discrepancy in fertilizer amount was not clear, but fertilization rates in this study were based on soil tests performed at the field trial location. Despite the variations in fertilizer amounts, results from Gresta et al. (2014) are the only published economic results for guar and will therefore be used for comparison.

To compare to Gresta et al. (2014), the baseline scenario was adjusted to use nitrogen- and phosphorous-based fertilizers at 260 and 175 kg per hectare (average of their two case studies), respectively, irrigation at 0.19 meters, seeding rate at 20 kg per hectare, and transportation and downstream processing were removed to match their system boundary of only farm costs. The resulting agricultural costs associated with guar were $730.38 per hectare These guar production cost results are lower than Gresta et al. (2014), however, are close to point-source data from Texas A&M AgriLife Extension[41]. Trostle (2020) states the guar seed contracted price in Brownfield, TX is $0.35 per kg-guar seed or $0.41 per kg-guar seed if delivered to the processing facility, which is more closely aligned with the baseline agricultural costs here of $0.49 per kg-guar seed or $503.69 per hectare. Although results from Trostle et al. (2020) are not as in-depth, they are more regionally and temporally appropriate, thereby representing a more accurate comparison. Economic comparison to Trostle (2020) indicates the need for further reduced costs to the agricultural process of this work to be more in line with the contracted pricing in Brownfield, TX.

2.3.2 *Environmental Analysis*

The environmental impacts of producing guar gum were modeled for the baseline scenario. Resulting impacts are shown in **Figure 2.4** with individual TRACI categories normalized to their respective totals. Total impacts for all categories are shown on the positive axis, normalized to 100%, and animal feed co-product displacement is on the negative axis, shown as percent of total impact. Net impact is shown using the diamond markers.

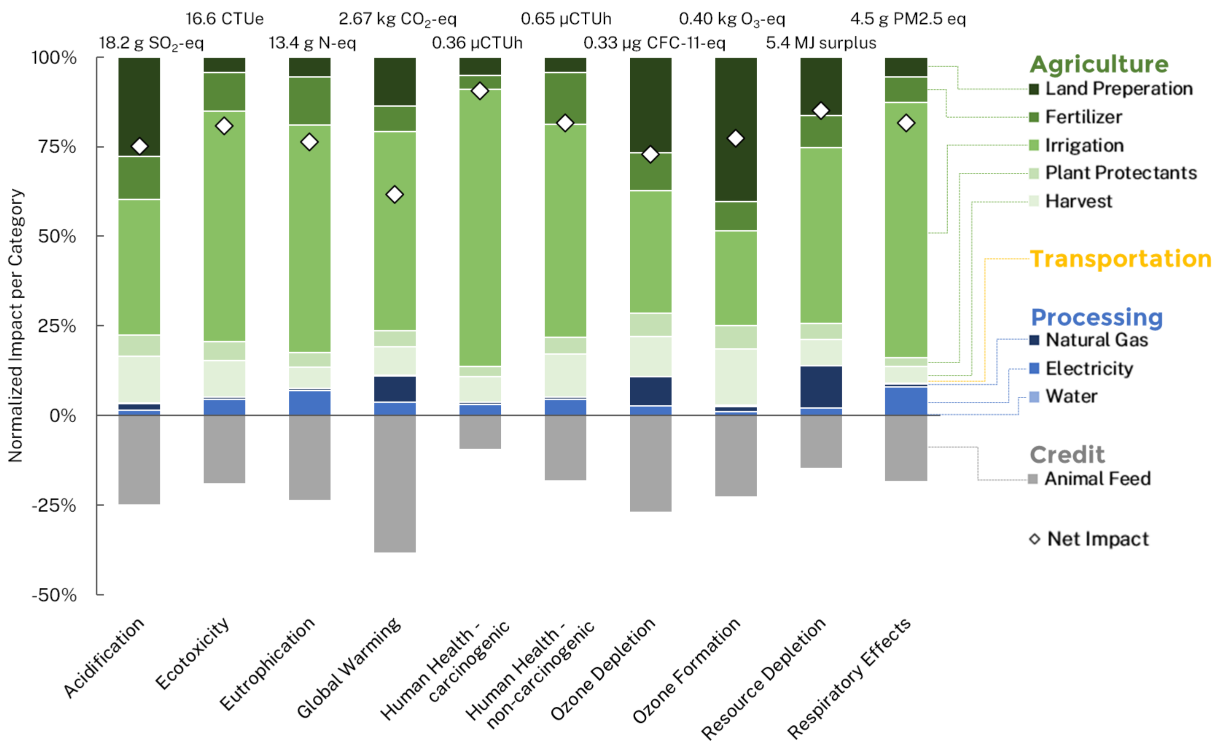

Figure 2.4: *Environmental impacts per kg-guar gum produced, aggregated in TRACI categories. Total values presented at the top of the figure represent net impacts, including animal feed displacement credit from the modeled baseline scenario. Results include agriculture (green), transportation (yellow), downstream processing (blue) and animal feed coproduct displacement credit (grey).*

Environmental contributions from agriculture, shown in green, account for between 86% and 97% of the total burden (non-net impact) in all categories. Within agriculture, irrigation and land preparation are the two largest contributors to most impact categories, specifically 55% and 14% for GWP, respectively. Irrigation includes embodied impacts from the materials comprising the sprinkler infrastructure (cast iron, polyvinylchloride and polyethylene), general agriculture equipment to maintain the system, associated storage for the equipment and direct emissions from electricity for pumping. The majority of the irrigation impact is attributed to electricity as sprinkler irrigation requires significant pumping. Land preparation includes the processes of rotary tilling, ploughing, and seeding and causes impact primarily due to diesel use and embodied emissions associated with the agricultural equipment performing the process (i.e. tractor and tilling equipment). Similar to the economic results, transportation, shown in yellow, contributed minimally to all categories due to the theoretically optimized location with respect to guar farms. Downstream processing, shown in blue, contributed between 3% and 14% to total impact (non-net impact), with natural gas and electricity being the primary inputs. The downstream processing facility requires very little material inputs, primarily because producing guar gum is largely a dry, mechanically-driven process. Thus, the majority of environmental impact stems from electricity and natural gas to operate various machinery, while water use contributes minimally overall. Within the extraction and conversion processes, heat treatment requires a substantial amount of steam which requires a large amount of natural gas. Within the conversion process, moisture needs to be removed from the finely flaked guar gum and is done so via a spray dryer which requires substantial amounts of electricity and natural gas.

2.3.2.1 Comparison to Existing Literature

Resulting GWP from the baseline scenario of 1,160 kg CO_2eq per hectare, for agricultural processes alone, is lower than several other crops grown in Arizona and New Mexico. Namely, crops such as alfalfa, wheat, barley and corn all have larger greenhouse gas emissions on a hectare basis, ranging 1,350 – 3,200 kg CO_2eq per hectare[42]. This indicates that adopting guar would result lower emissions than some of the existing crops grown in the American Southwest.

The baseline GWP was also compared with environmental impact results from Gresta et al. (2014). Farm-level GWP from the baseline scenario is lower than the range presented from Gresta et al. (2014) of 2,751-2,906 kg CO_2eq per hectare. However, the higher results of their work can mostly be attributed to the higher fertilizer, irrigation, and seeding amounts mentioned in 3.1 Economic Analysis. For comparison to Gresta et al. (2014), the baseline scenario was modified by adopting their fertilizer, irrigation and seeding amounts as well as aligning the system boundary as described previously (see 3.1.2 Comparison to Existing Literature). The resulting GWP was 2,175kg CO_2 per hectare which is much closer to results of Gresta et al. (2014).

2.4. Discussion

The MSP from the baseline scenario of $1.44 per kg-guar gum is higher than the five-year average U.S. import price for guar gum ($0.99 per kg-guar gum), as shown in **Figure 2.2**. It is important to note that the five-year average U.S. import price is a market price and not a production price and therefore may include some nontransparent supply-chain margins beyond an MSP. However, this market price provides the only comparison for guar gum MSP because there are no cradle-to-gate guar gum prices reported in literature or publicly available U.S production prices. Although the resulting baseline guar gum MSP is higher than the five-year average U.S. import price, adjusting modeling inputs and practices to represent various future scenarios may lower it significantly.

The baseline scenario represents a single, theoretical set of inputs using averages of field trial data. As a result, the baseline scenario may not represent specific growing conditions. Individual field trial data were used to develop Figure 5, illustrating trends from specific growth conditions with varying irrigation amounts and seed yields. Results were determined for the average of eight replicates across four irrigation amounts and the error bars represent the maximum and minimum values observed. The figure shows a correlation between increased irrigation amount and increased MSP and GWP. These correlations were observed largely because the slight upward trend in seed yield, when increasing irrigation amount, was not enough to recover the costs or environmental impacts. Future work should consider maximizing yield under a wider range of irrigation scenarios, including zero irrigation conditions.

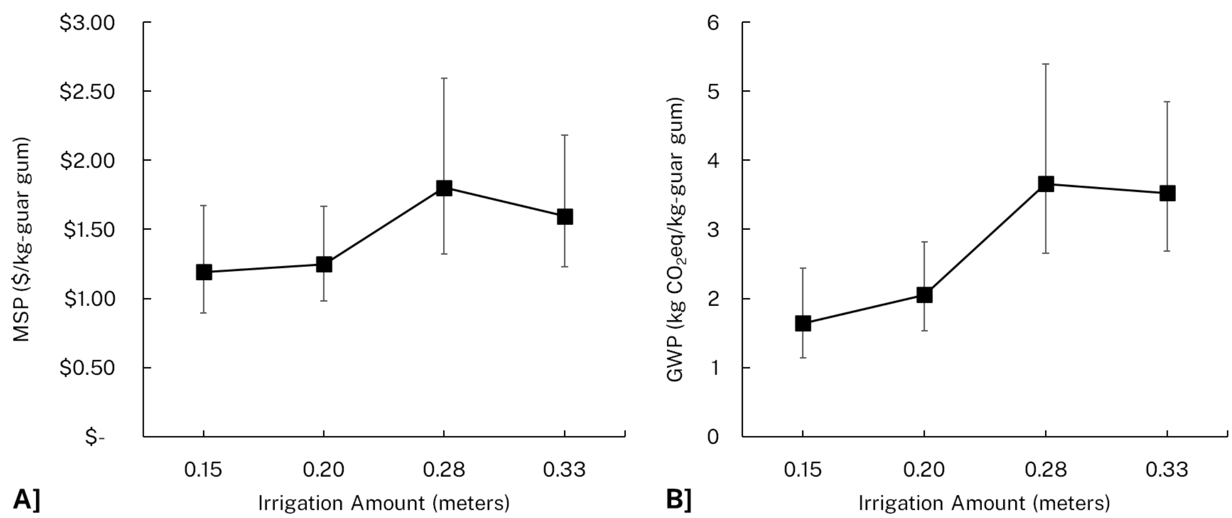

***Figure 2.5**: Economic (MSP), panel A], and environmental impact (GWP), panel B], of varied irrigation amount from experimental field data. The error bars represent standard deviation for guar seed yield across eight field trial replicates.*

In addition to irrigation, other input parameters of the baseline analysis may be altered in specific cultivation scenarios. Highlighted in Figure 6 is a best case MSP for guar gum based on potential changes, both material and operational, from the baseline scenario. In the figure, modifications to the baseline scenario were made while holding the guar seed yield constant resulting in a best case scenario MSP of $0.45 per kg-guar gum. Modifications include removing irrigation, removing fertilizers, changing to lower cost plant protectant (herbicides) and improving land management practices. These changes reflect actual best operating practices from specific commercial farmers that are currently growing guar. However, limited specifics have been collected on these practices and Figure 6 should be considered the hypothetical result of a best case scenario.

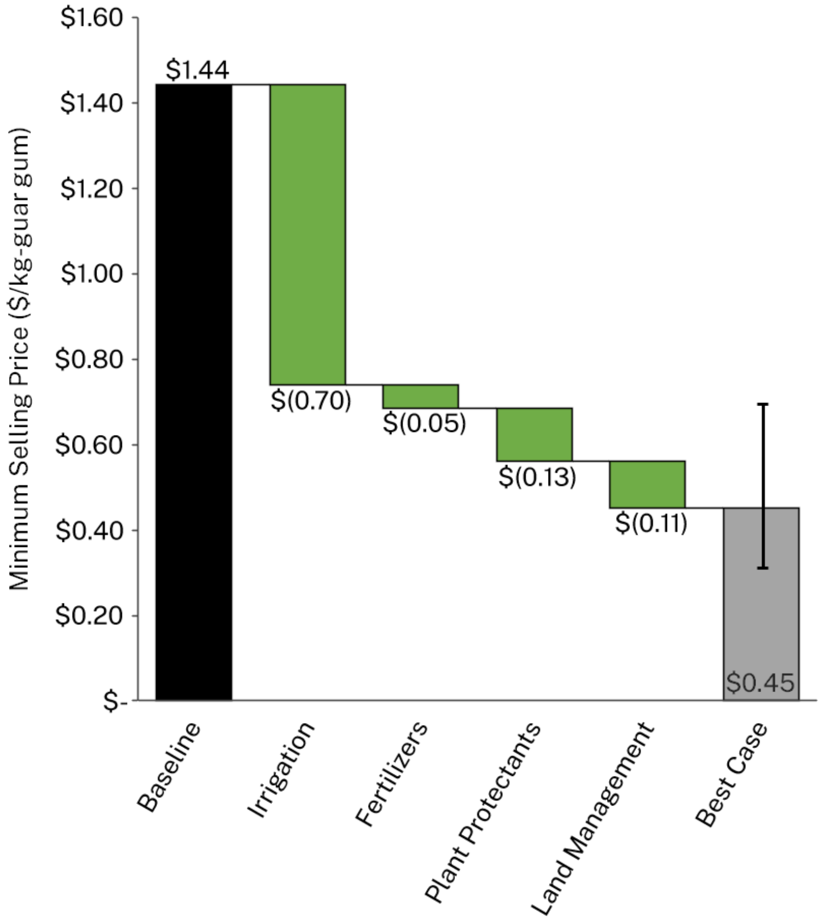

Figure 2.6: *Best case scenario MSP of guar gum resulting from changing material inputs and operational practices, while holding guar seed yield constant. The range shown on the best case scenario MSP illustrates the impact of varying guar gum yield by ±20%. The five-year average U.S. import price is $0.99 per kg-guar gum.*

The irrigation amount was set at zero in the best case scenario to understand the significance on MSP, as indicated in **Figure 2.5**. Despite removing irrigation, the guar seed yield was held constant from the field trials data at 1,024 kg per hectare as literature shows similar yields without irrigation (average of 1,002 kg per hectare in West Texas)[43]. Additionally, Undersander et al., 1991 state that guar is grown without irrigation in areas that receive between 0.25 and 1.0 meters of rain and Arizona and New Mexico receive 0.33 meters and 0.36 meters, respectively. Therefore, it is reasonable to assume a zero irrigation scenario with the same guar seed yield observed in the baseline scenario. The impact of removing irrigation was a reduction of $0.70 per kg-guar gum (49% of the baseline MSP) to a new MSP of $0.74

per kg-guar gum which is lower than the five-year U.S. import average. Fertilizers, both nitrogen- and phosphorous-based, were applied in the baseline scenario. However, typically these inputs are coupled with irrigation, meaning if no irrigation is applied, neither are fertilizers. This is because farmers tend to only supplement irrigation and fertilizer on high rainfall years to increase yield which would ideally offset the cost of both inputs. During normal or low rainfall years, as in the case of the field trials data used in **Figure 2.5**, the costs of irrigating and fertilizing to increase yield will not be recovered. Removing the nitrogen- and phosphorous-based fertilizers resulted in a reduction of $0.05 per kg-guar gum (3% of the baseline MSP). Several herbicides have been used in guar cultivation, with Treflan and Brawl H2O used in the baseline scenario. For the best case scenario, the costs of both herbicides were lowered to cheaper products with similar function, Clethodim and 2,4 DB, lowering the MSP by $0.12 per kg-guar gum (8% of the baseline MSP). Lastly, best management practices were applied to the land preparation steps by simplifying tilling to a one-pass plow and drag operation. Changing tilling operations resulted in lowering MSP by $0.11 per kg-guar gum (8% of the baseline MSP).

The results of the best case guar gum scenario indicate that guar has the potential of being produced for $0.45 per kg-guar gum. The range shown on the best case guar gum result of **Figure 2.6** are a result of ranging guar seed yield by ±20%, or between 819 kg per hectare and 1,229 kg per hectare which results in $0.69 per kg-guar gum and $0.31 per kg-guar gum MSP's, respectively. This further illustrates the importance of guar seed yield, but also shows that even with a reduction of 20% seed yield, the MSP is still lower than the five-year average U.S. import price of $0.99 per kg-guar gum, shown in **Figure 2.2**. Additionally, agricultural costs (removing transportation and downstream processing) from the best case scenario are $0.20 per kg-guar seed which are much lower than those from Trostle (2020) at $0.35 per kg-guar seed[41]. Results of the best case scenario indicate that guar has the potential to be grown in the arid southwest for less than current contract prices in West Texas and guar gum has the potential to be produced for less than U.S. import prices with modifications made to the baseline scenario, namely the removal of irrigation.

The environmental impacts of the best case scenario were also investigated. Removing irrigation, removing fertilizers, switching herbicides, and improving land management practices resulted in GWP reductions of 2.39, 0.31, 0.02, and 0.11 kg CO_2 eq per kg-guar gum, respectively. The best case scenario GWP was –0.17 kg CO_2 eq per kg-guar gum (see Figure A.5 for all other environmental impact categories). This resulting negative GWP value indicates that the net greenhouse gas emissions from displacing soybean meal with guar meal is greater than the greenhouse gas emissions associated with the entire best case cradle-to-gate guar gum process.

2.3. Conclusions

An integrated TEA and LCA was developed for the process of producing guar gum in the arid, southwestern United States of Arizona and New Mexico. Modeling input parameters were based on experimental field trials data, focused on irrigation impact on guar seed yield, with the baseline scenario representing average data. Economic results of the baseline scenario indicate a guar gum MSP needed to recover costs of production for a thirty-year life of $1.44 per kg-guar gum. The largest contributors to the baseline MSP were irrigation and plant protectants (both the material and application costs). The environmental results from a cradle-to-gate LCA indicated that irrigation and land preparation (rotary tilling, ploughing, and seeding) were the largest contributors to the majority of environmental impact categories. Particularly, results from the baseline scenario indicate a GWP of 2.67 kg CO2eq per kg-guar gum, with irrigation and land preparation contributing 55% and 14%, respectively. When compared to other existing crops grown in the region, guar had similar or less emissions than alfalfa, wheat, barley, and corn. A sensitivity analysis performed on all modeling input parameters showed that individually, harvest yield has the biggest impact on MSP. Scenario analyses performed on field trials data focused on understanding impact of varying irrigation amount and showed that the slight increase in guar seed yield from increased irrigation was not enough to make up for its cost or environmental impact. Both guar gum MSP and GWP increase with increasing irrigation amounts. A best case scenario was developed in which several inputs and processes were altered, while holding guar seed yield constant, to understand a potentially attainable, commercial MSP of guar gum. These alterations include removing irrigation and fertilizers, switching to low cost herbicides and minimizing tilling, resulting in a best case scenario MSP of $0.45 per kg-guar gum which is lower than the five-year average U.S. import price of $0.99 per kg-guar gum.

CHAPTER 3: THE GREENHOUSE GAS EMISSIONS OF INDOOR CANNABIS PRODUCTION IN THE UNITED STATES[b]

3.1. Main

Understanding the greenhouse gas (GHG) emissions of commercial cannabis production is essential for consumers, the general public, and policy makers to improve decision-making in order to mitigate effects of climate change. Since recreational legalization was pioneered in Colorado in 2012, the U.S. legal cannabis industry has rapidly grown from $3.5 billion USD industry to $13.6 billion USD in annual sales with states like Colorado selling more than 530 metric tons of legally grown cannabis product every year[44,45]. Additionally, with 48% of adults in the U.S. having tried cannabis at some point in their life and 13% of adults having consumed in the last year, substantial demand exists at the consumer level[46]. In light of its rapid growth and widespread use, there is minimal quantitative understanding of the GHG emissions from legal indoor cannabis cultivation.

The initial amendment legalizing recreational cannabis in Colorado required the majority of cannabis product to be sold at a collocated retail location[47]. This restriction led to cultivation practices occurring within the city limits of Denver, CO. This, along with security, theft, and quality concerns, consequently led to the cultivation of cannabis indoors. While data of the exact amount of cannabis by cultivation method is not currently publicly available for the U.S., a recent survey of producers in North America shows that 41% of respondents indicated that their grow operations occur solely indoors[48]. It is well known that indoor cannabis cultivation requires significant energy input, reflected in high utility bills and industry reports[47,49–52]. However, many of these large energy loads, along with other material inputs required to cultivate indoor cannabis, have not yet been equated to GHG emissions.

Previous reports have performed rudimentary quantifications of GHG emissions from indoor cannabis by equating electricity use from monthly bills[49,50]. However, this approach omits additional GHG

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[b] This chapter was published as a peer-reviewed journal article, material from: Summers, H.M., Sproul, E. & Quinn, J.C. The greenhouse gas emissions of indoor cannabis production in the United States. Nat Sustain (2021). https://doi.org/10.1038/s41893-021-00691-w

emissions from other energy sources such as natural gas, upstream GHG emissions from production and use of material inputs and downstream GHG emissions from handling of waste. The most thorough report quantifying GHG emissions from indoor cannabis is from Mills[53], which states that growing one kilogram of cannabis indoors releases 4,600 kilograms of carbon dioxide equivalent (CO_2-eq). However, the scope of the work was intended to be a central estimate, representing a singular U.S. location case study for the industry's general practices. The work from Mills[53] was also done prior to legalization and only utilized data from small-scale experimental systems, thus lacking validation of full-scale commercial grow operations. Since Mills[53], minimal research has been done to improve GHG emissions quantification or to investigate geographic effects of growing indoor cannabis. In order to fill this knowledge gap, this study quantifies GHG emissions of commercial indoor cannabis production using life cycle assessment (LCA) methodology and expands scope to include geographic effects across the U.S.

An indoor cannabis cultivation model was developed to track the necessary energy and materials required to grow cannabis year-round in an indoor, warehouse-like environment. This environment maintains climate conditions as required for the cannabis plants, yielding a consistent product regardless of weather conditions. The model calculates the necessary energy to maintain these indoor climate conditions based on a year's worth of hourly weather data from more than 1,000 locations in the U.S.[54]. The analyzed locations are independent of current legal status and represent hypothetical grow facilities in all 50 U.S. states. The model then converts the required energy, supplied from electricity and natural gas, to GHG emissions through electrical grid emissions data from 26 regions in the U.S.[55] and life cycle inventory (LCI) data[37,38]. Additionally, the model accounts for the upstream, or cradle-to-gate, GHG emissions from the production and transportation of material inputs such as water, fertilizers, fungicides, bottled carbon dioxide (CO_2) supplied for increased plant growth, waste to a landfill, and other required grow operations consumables. The resulting cumulative GHG emissions for annual indoor cannabis cultivation across the U.S., represented as kilogram CO_2-eq per kilogram of dried cannabis flower, is presented in Figure 3.1a.

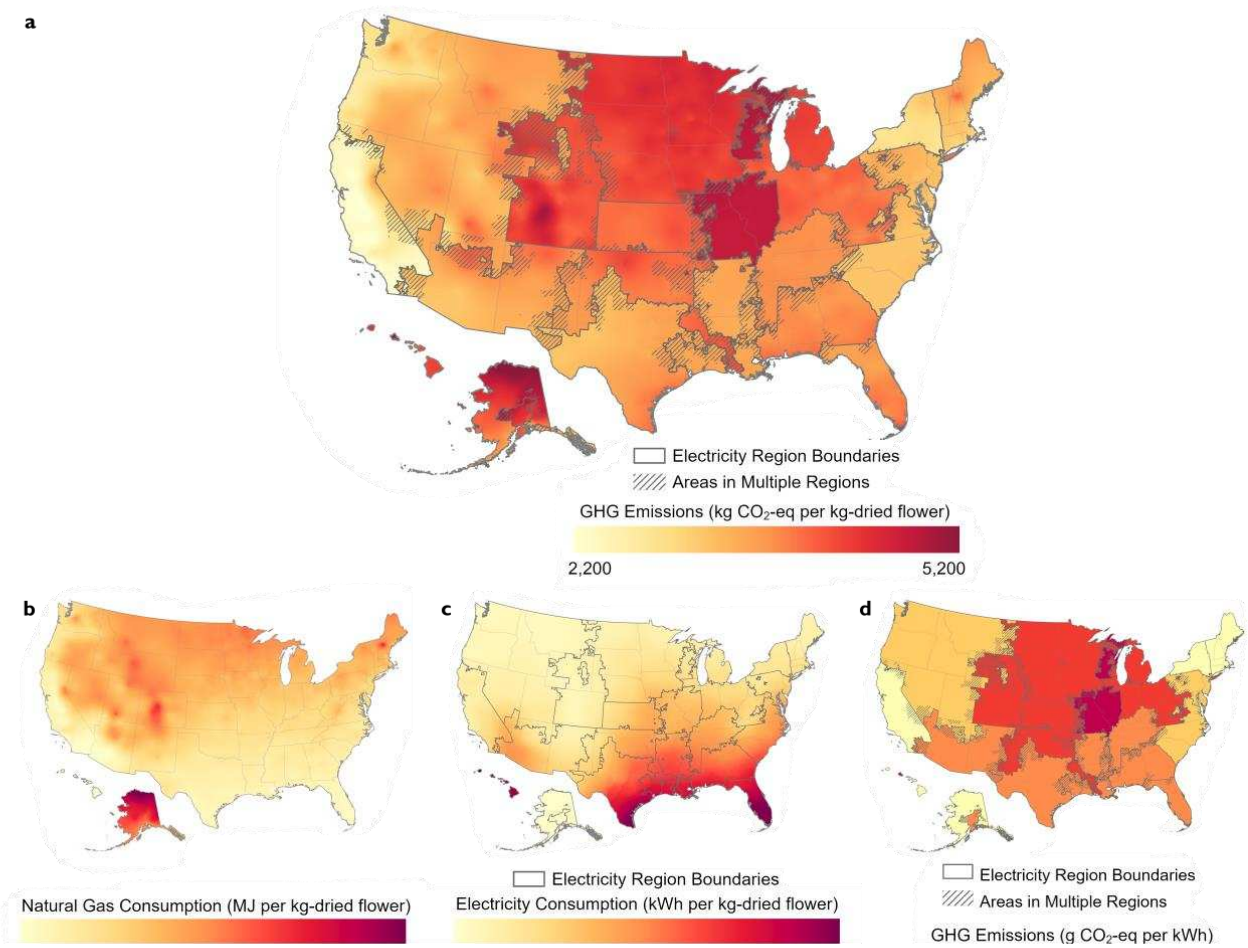

Figure 3.1: *The life cycle greenhouse gas (GHG) emissions and energy intensities from indoor cannabis cultivation modeled across the U.S. a, Cumulative GHG emissions from cultivating cannabis indoors interpolated within eGRID electricity region boundaries (kg CO_2-eq per kg-dried flower), b, Natural gas required (MJ per kg-dried flower) to maintain indoor environmental conditions; c, Electricity required (kWh per kg-dried flower) to maintain indoor environmental conditions and high-intensity grow lights, d, GHG emissions for the U.S. electricity regions modeled (g CO_2-eq per kWh). Full resolution figures are in Appendix Figures B.1 through B.4.*

The results for Figure 3.1a are a combination of modeled natural gas consumption (Figure 3.1b), electricity consumption (Figure 3.1c) combined with geographically resolved GHG emissions for electric grid mix (Fig. 1d), and upstream and downstream GHG emissions. Resulting GHG emissions range from 2,283 to 5,184 kg CO_2-eq per kg-dried flower, observed in Long Beach, CA and Kaneohe Bay, HI, respectively, with a median value for all locations analyzed of 3,658 kg CO_2-eq per kg-dried flower. As these results are independent of current legal status within individual states, these findings should not be interpreted to represent the current reality of the industry. More so, the results represent GHG emissions if the cultivation method in each location were selected to be indoors.

The results in Figure 3.1 show that a wide variation of GHG emissions from indoor cannabis cultivation exists across the U.S. Regional trends show that areas such as the Mountain West and Midwestern U.S. are especially intensive for growing cannabis indoors. To better understand the factors that lead to variations in GHG emissions across the U.S., Figure 3.2 illustrates contributions to the total GHG emissions for ten geographically and meteorologically diverse locations. The locations of Figure 3.2 capture the full range of GHG emissions results, from the minimum of Long Beach, CA to the maximum of Kaneohe Bay, HI, with a single location selected from the regions of Pacific Northwest, Pacific Southwest, Desert Southwest, Northeast, Southeast, Mountain West, East North Central, West North Central, Alaska and Hawaii. In addition, these ten locations represent large populations within U.S. states that have legalized cannabis sales (either medical, recreational or both) and are in unique electricity regions. Results are shown on a per kg-dried flower basis as total production quantities and cultivation method data are not publicly available. Across each location, GHG emissions were divided into process categories to understand the largest contributors. Despite geographic variations, certain variables were shown to be consistently large contributors to overall GHG emissions. These variables include indoor environmental controls via heating, ventilation, and air conditioning (HVAC) required to maintain indoor temperature and humidity, as well as high-intensity grow lights and the supply of CO_2 for increased plant growth.

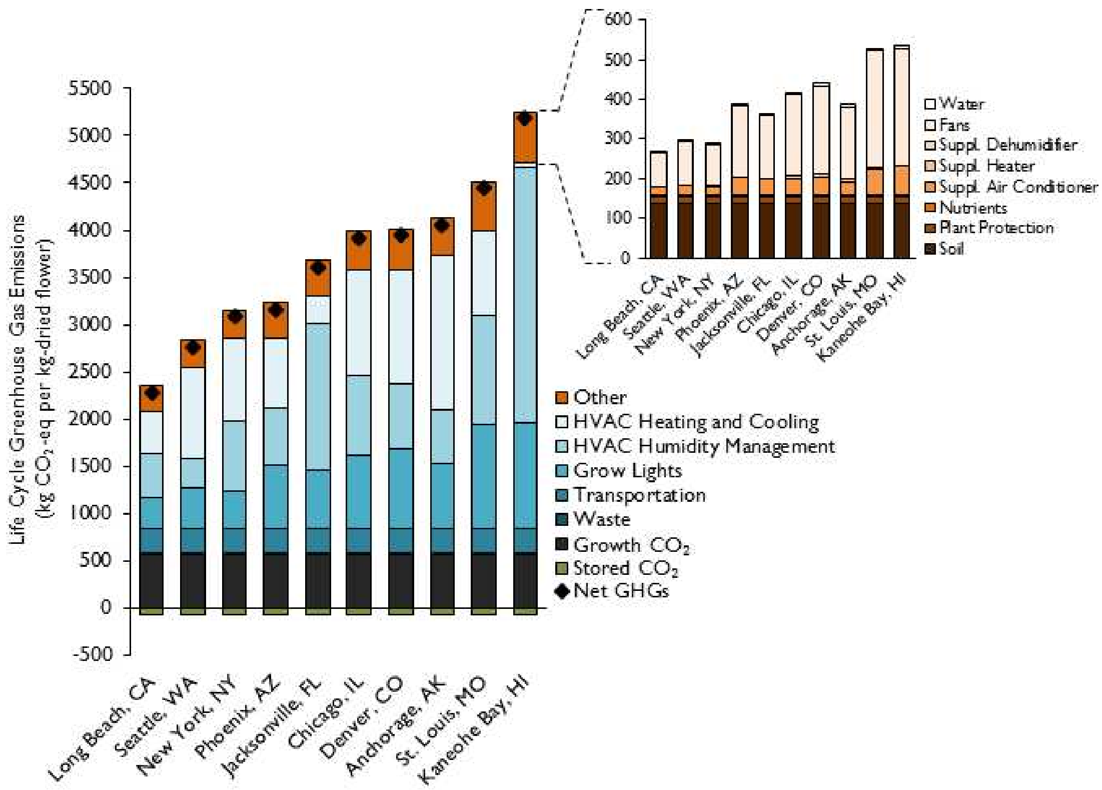

Figure 3.2: *Breakdown of life cycle GHG emissions contributions from indoor cannabis cultivation. GHG emissions, presented on a kg-dried flower basis, from indoor cannabis production at ten of the 1,011 locations modeled. The GHG emissions totals represent individual simulation results based on modeling input parameters specific to each location. Heating, ventilation, and air conditioning (HVAC) labels in the main figure refer to major equipment used to manipulate outside air to meet inside condition criteria whereas the indoor environmental controls in "other" are supplemental (suppl.) systems which represent additional equipment located inside grow rooms that aid in maintaining environmental conditions.*

The HVAC systems are responsible for modifying air temperature and humidity to an allowable range before being supplied to the cannabis plants. This is critical to maintaining plant health as sudden changes in temperature and humidity can shock the plants and ultimately lead to crop damage and product loss. Additionally, cannabis plants require a regular supply of fresh air to help moderate humidity and oxygen levels. This work assumes 30 volumetric air changes per hour (ACH). This value represents the average value from literature, which reports values as high as 60 ACH and as low as 12 ACH (see Appendix Table B.1). For comparison, recommended ventilation for homes is 0.35 ACH and operating rooms in hospitals requires a minimum of 15 ACH[56,57]. Air condition modifications and supply via HVAC are cumulatively shown to be the largest contributor to overall GHG emissions regardless of location (see Appendix Table B.2 for all contributions). The contributions of GHG emissions from HVAC also infer that locations with lower GHG emissions are better suited meteorologically for indoor cannabis cultivation than locations with large GHG emissions as fewer modifications to the outside air conditions were required.

Categorized in Figure 3.2 are HVAC processes that include modification to air humidity, labeled as HVAC humidity management (latent loads), and air temperature, labeled as HVAC heating and cooling (sensible loads). These processes represent annual energy demand for modifying air delivered to all stages of plant life cycle including clone, vegetative, flowering and curing (also known as drying). HVAC humidity management largely depends on geographic variability, as in the case of Jacksonville, FL and Kaneohe Bay, HI, where dehumidifying the consistently hot and humid outside air to desired temperature and humidity ranges requires significant energy through electric HVAC equipment. HVAC heating and cooling of air are shown to be major GHG emissions contributors in geographic locations where humidity ranges are acceptable, but average outside temperatures are consistently different from those of the desired indoor requirements for cannabis plants (15.6 – 29.4 °C). These conditions are observed most significantly in Denver, CO and Anchorage, AK. Results, as illustrated in Figure 3.2, also indicate that at some locations, the supplied air conditions from HVAC at 30 ACH are sufficient to overcome the increased heat and humidity from lights and plants, respectively, while other locations require the use of additional supplemental equipment to keep inside conditions within tolerance. This categorization of supplemental environmental control equipment is shown in the breakdown of “Other,” as supplemental dehumidifiers, air conditioners and heaters. This equipment turns on in the model when the HVAC equipment cannot maintain acceptable temperature and humidity ranges via the air supply rate of 30 ACH. All the supplemental systems were modeled as having an electric power supply and are cumulatively shown to have a minor contribution to overall GHG emissions at the modeled air exchange rate. Specifically, for the ten locations of Figure 3.2, the supplemental dehumidifiers were never operated because the frequency of ACH was able to maintain the required indoor humidity levels. Additionally, the supplemental heaters and air conditioners ranged in use, but contributed less than 2% of the total GHG emissions in all locations.

The second significant GHG emissions contributor observed universally is from high-intensity grow lights. Lighting intensities for cannabis plants can range from 50-200 times higher than a typical office setting and are run for 12, 18 or 24 hours depending on plant stage of life[53]. In all locations analyzed, indoor lighting requirements were held constant and therefore the required annual kilowatt-hours (kWh) of electricity are constant. However, the GHG emissions associated with electricity production range by more than six times based on geographically varying electric grid mixes, as shown in Figure 3.1d. These variations in grid GHG emissions are most clearly observed in Figure 3.2 between Kaneohe Bay, HI where the grid mix is largely oil based (805 g CO_2-eq per kWh) and Long Beach, CA where natural gas and solar power are much more prevalent (238 g CO_2-eq per kWh).

Lastly, supplemental CO_2 contributes significantly to overall GHG emissions and does so equally across all locations analyzed as it is a fixed input that is independent of geography. CO_2 is introduced to the indoor grow environment to increase plant photosynthetic activity therefore allowing plants to reach maturity sooner[58]. In these results, the contributing GHG emissions from the introduction of gaseous CO_2 is not from the CO_2 itself, but rather from the production processes associated with the compression of the gas into liquid form where it is then stored within a cylinder. The sourced CO_2 gas itself is obtained free of environmental burden as it is typically received as a byproduct of another process such as ammonia production[38]. It was also assumed that if the cannabis industry were not using the CO_2, it would be released to the atmosphere and therefore the physical CO_2 gas itself does not count as a penalty to the cannabis facility.

The results of Figure 3.2 indicate that more than 80% of GHG emissions for these locations are generated via practices that are non-traditional for agricultural products. Traditional agricultural cropping systems typically see the largest GHG emissions from practices associated with land preparation and management or fertilizer, but for indoor cannabis these values are less than 5% of the total on average[59].

This is not to say that values from these traditional practices are lower in indoor cannabis cultivation but that the significant energy required to create an artificial climate for plants indoors causes cannabis to be extremely GHG emissions intensive.

3.1.1 Interpretation for Improved Decision Making

The detailed results from this work enable specific recommendations on how the environmental burden of indoor cannabis cultivation can be reduced through engineering solutions as well as policy. Results from the high resolution, geographically resolved model identify specific aspects of indoor growth that lead to substantial GHG emissions. This insight can be applied to states with existing legal indoor practices and during policy and regulation development prior to individual state legalization.

For states that have already legalized medical and recreational cannabis, these results can be used to better understand what processes are the largest contributors to overall GHG emissions and therefore focus efforts toward modifying current practices to reduce GHG emissions. Namely, these findings can be used to develop best management practice guides similar to those of O'Hare et al.[50], Gill[60] and The Cannabis Sustainability Working Group[61]. Results of this work can also help inform policies such as the recent California Statewide Codes and Standards Enhancement Program proposal[62] that would require all indoor cultivation to switch to LED lights by 2023 or House Bill 1438[63] in Illinois that limits lighting intensities and requires producers to commit to using high-efficiency HVAC equipment. With the quantitative GHG emissions results from this work, best management guides should include practices to specifically reduce GHG emissions from HVAC operations, high-intensity grow lights and supplemental CO_2 as these are the largest contributors in the majority of U.S. locations.

In addition to holistic process changes, an uncertainty assessment through sensitivity analysis was performed to identify individual input parameters that result in large changes to GHG emissions in response to variation of an input value. Results indicate that the most sensitive variable was plant yield (kg-dried flower per plant) which was foreseeable as GHG emission results are presented on this basis (see Appendix Figure B.5 for full results). Besides plant yield, ACH was the next most sensitive variable as this parameter is directly coupled with HVAC energy requirements and supplemental CO_2 amounts. In this work, 30 ACH was selected and held constant for all hours of operation within the indoor cannabis growth model based on a literature survey which is summarized in Appendix Table B.1. Further investigation into this high impact variable indicates that ranging ACH from 10 to 60 can result in a GHG emissions difference of more than 230% depending on geographic location, **Error! Reference source not found.**3 (see Appendix Table B.11 for full results). It is also important to note that choosing the minimum ACH for each location may not necessarily be optimal as moisture needs to be removed from grow rooms to avoid mold and ultimately loss of product. Furthermore, the relationship between ACH and GHG emissions from indoor cannabis is nonlinear in many locations due to varying equipment use and therefore energy demand. Specifically, the use of supplemental equipment declines moving from 20 to 30 ACH because the indoor climate requirements are met by the increased supply of fresh air conditioned through HVAC equipment. Therefore, ACH warrants particular attention when developing best management practice guides for individual cultivation facilities or geographic regions. Results of the sensitivity analysis also identified temperature and humidity ranges, typically measured in facilities as vapor pressure deficit, and CO_2 concentrations as the next three most sensitive variables to overall GHG emissions. All three of these parameters are coupled with ACH and although they would benefit from individual optimization, they reiterate the importance of optimizing ACH.

Results of this work also identify geographic regions within the U.S. and individual states where indoor cannabis cultivation would have low GHG emissions. Federal restrictions limit the transport of cannabis across states and therefore a U.S.-wide geographic optimization for growth locations is not feasible. However, in most U.S. states, intrastate transport of cannabis product is legal and therefore, if indoor cultivation is to remain within that state, this work highlights locations for indoor cannabis cultivation that would lead to lower GHG emissions. These geographic variations are most noticeable in Colorado where the mountainous locations of Leadville, Aspen, Gunnison, and Alamosa lead to significantly more GHG emissions than locations on the plains of Pueblo, Trinidad, or Denver. For example, the practice of growing in Leadville leads to 19% more GHG emissions than Pueblo. The savings in GHG emissions from moving indoor cultivation to Pueblo and away from Leadville are likely to be much greater than the GHG emissions of transporting the final product to retail locations in Leadville. These results indicate that individual states can optimize their indoor cultivation locations to reduce GHG emissions. Laws may need to change for this geographic optimization to occur, such as the previously mentioned law in Colorado that stated cultivation and retail facilities to be collocated. For states that have yet to legalize, flexibility with collocation requirements could improve the GHG emissions from the standpoint of intrastate geographic optimization.

Additional conclusions from this work can help inform policy for states where cannabis cultivation is not yet legal. For these states, developing policy to encourage greenhouse and outdoor cultivation can drastically reduce GHG emissions by avoiding the practice of indoor cannabis cultivation altogether. The authors acknowledge that shifting cannabis cultivation outdoors is not free of environmental burden as literature has shown several concerns including increased irrigation, excessive use of pesticides and nutrient runoff[51,64]. Additionally, switching to greenhouse and outdoor practices requires appropriate regulation to avoid the potential encouragement of illicit practices which historically have led to additional environmental burden such as illegal water diversion and deforestation[51,64]. There are also concerns with greenhouse and outdoor cultivation associated with security, inability to achieve multiple harvests per year and lack of consistent product.

Although there are many hurdles associated with shifting cannabis growth to legal and well-regulated greenhouse and outdoor cultivation practices, preliminary studies have investigated the potential difference in GHG emissions when switching to greenhouse and outdoor cultivation practices with results indicating reductions of 42% and 96%, respectively[49,50]. It is important to note that these reports are limited in scope and resolution as the GHG emissions are based primarily on electricity consumption through monthly bills. Therefore, the current state of the industry would benefit from understanding the true differences between GHG emissions of greenhouse and outdoor cultivation at a similar resolution to the work presented here. Results of this study affirm that more than 80% of the GHG emissions from all indoor cannabis locations assessed are caused by practices directly linked to indoor cultivation methods, specifically indoor environmental control, high-intensity grow lights, and supply of CO_2 for increased plant growth. If indoor cannabis cultivation were to be fully converted to outdoor, these preliminary estimates show that the state of Colorado, for example, would see a reduction of more than 1.3% to the state's annual GHG emissions (2.1 million metric tons of CO_2-eq)[65]. These GHG emissions are on par with entire sectors within the state such as coal mining, waste management and industrial processes which are responsible for 1.8, 4.2 and 4.5 million metric tons of CO_2-eq annually, respectively[65].

Conclusive results quantified in this study indicate that cultivating cannabis indoors leads to considerable GHG emissions regardless of where it is grown in the U.S. These results illustrate the need for change within the rapidly growing cannabis industry in order to reduce GHG emissions from indoor cultivation.

3.2 Methods

3.2.1 Model scope

Indoor cannabis cultivation facilities vary in the way they are built and operate depending on existing building infrastructure, codes and permitting, and geographic considerations pertaining to HVAC equipment selection. Further variation is seen from the specific strain of cannabis being cultivated, leading to different desired indoor cultivation climates. Modeled here is a representative facility of common indoor cannabis cultivation practices established through literature research and industry communication. The system boundary of the model represents a cradle-to-gate framework, encompassing operations associated with the warehouse-like facility to support indoor cannabis cultivation, including necessary energy and material inputs as well as waste from the facility (see Appendix Figure B.6). Downstream activities such as transportation of final product to point-of-sale, packaging, use and end-of-life were not considered.

3.2.2 Model development and resolution

The modeled indoor cultivation facility operates around the four primary cannabis stages of life – clone, vegetative, flower and curing – with permanent rooms established for each to house the necessary equipment and maintain required growing environments. Operations are similar to an assembly line because established room environments are maintained constant while plants rotate through depending on stage of life (see Appendix Figure B.7). The length of each plant stage was modeled using average durations from Colorado indoor growers as 22, 50, 57 and 14 days for clone, vegetative, flower and cure, respectively[44]. Because flowering is the longest stage, it creates a bottleneck effect. This effect was accommodated by determining when all other stages of life should start and end relative to flowering, resulting in an average of 6.2 harvests per year. Additionally, the maximum number of cannabis plants flowering in the allotted grow space was limited, representing a conservative GHG emissions estimate since results are presented on yield, kg-dried flower, basis. Once the grow room timing was established, the model determined what climate modifications were needed to maintain a steady cultivation environment based on required indoor air temperature, humidity, and the outside conditions of the simulated location. Appendix Figure B.8 illustrates a typical layout for a single grow room demonstrating the array of equipment necessary to perform these climate modifications.

The first series of model calculations quantified the necessary energy to modify outdoor air conditions, performed via HVAC, to meet required temperature and humidity ranges of the grow room. Existing outdoor air conditions were provided on an hourly resolution using the 3rd edition of typical meteorological year datasets from National Renewable Energy Laboratory (NREL)[54]. Each stage of plant life requires different indoor environmental conditions and the desired temperature and humidity ranges that were modeled are listed in Appendix Table B.3. HVAC energy calculations were based on psychrometric principals of thermodynamics while accounting for the appropriate ambient pressure relative to location elevation. The air exchange rate, modeled at a fixed rate of 30 ACH for all hours of grow operation, was obtained through a literature survey resulting in values ranging from 12-60 ACH (see Appendix Table B.1). Resulting natural gas and electricity consumption was determined from the modeled HVAC energy requirements assuming a combustion heating efficiency of 80%[66] and an electric cooling coefficient of performance of 3.25[67].

The model then determined temperature and humidity values for the mixing of delivered HVAC air with existing inside growth conditions as well as operations occurring in the grow room. Operations occurring inside included added heat from high-intensity grow lights, heat loss or gain through the walls and added moisture to the room via plant evapotranspiration[68] (see Appendix Table B.4). Calculations of these events were based on the inside heat transfer and thermodynamic methodologies of greenhouse models found within literature with appropriate modifications made to represent warehouse-like facilities[68,69]. The model quantified resulting temperature and humidity values inside the grow room which were used to determine whether supplemental environmental control equipment, located inside grow rooms, was needed to keep inside climate within the conditions listed in Appendix Table B.3. The supplemental equipment modeled was assumed to be electrical and included air conditioners, dehumidifiers, and heaters. Further description of energetic calculations for climate modification are provided in Appendix Method B.1 and Appendix Figure B.9. Additional electric-based equipment was modeled including high-intensity grow lights, circulating fans (which were assumed to be on anytime plants are in a grow room), water pumps, and water heaters (see Appendix Table B.5). The model determines, on an hourly resolution, the annual electricity and natural gas required to cultivate cannabis indoors at each location (see Appendix Table B.12).

Beyond electricity and natural gas, material inputs such as supplied CO_2, water, fertilizer, pesticides and fungicides were also modeled. Supplied CO_2 was added to grow rooms when the high-intensity grow lights were on and concentrations were held at the values listed in Appendix Table B.3 throughout air exchanges. Water was applied via drip irrigation at an average rate of 3.8 liter per plant per day[70]. Pumping power for water delivery was modeled at a rate of 0.73 watt-hours per liter[39]. Nutrients, in the form of nitrogen, phosphorous, and potassium fertilizers, were supplied via the drip irrigation system in varying amounts and times (amounts and schedule provided in Appendix Table B.6)[71]. Cumulatively, the detailed energy and material inventory from the indoor cannabis model serves as the foundation for the environmental assessment.

3.2.3 Environmental analysis

The indoor cannabis cultivation model accounts for all operational energy and materials needed to grow plants from infancy through dried retail-ready product in an indoor, warehouse-like setting. The required energy primarily stems from HVAC equipment and lighting and is provided through electricity or natural gas. The materials inventory consists of inputs such as water, fertilizers, pesticides, fungicides and supplemental CO_2. Energy and material inventory was translated to GHG emissions through attributional LCA methodologies[2,3] with results presented for a cradle-to-gate, per kg-dried flower, system boundary (see Appendix Figure B.6). All GHG emissions were allocated to the dried flower assuming 6.2 harvests per year[44] and an assumed yield of 0.44 kilograms of dried flower per plant[53].

From the indoor cannabis model, electricity was quantified for 1,011 U.S. locations and resulting annual kilowatt-hours were cross-referenced with geographically specific GHG emission data to appropriately capture variations in electrical grid mix (see Appendix Figure B.10 for all U.S. locations analyzed). Geographically resolved GHG emissions data for electricity generation was obtained from the Environmental Protection Agency's (EPA) Emissions and Generation Resource Integrated Database (eGRID)[55] (see Appendix Table B.7 and Appendix Figure B.11). Electric grid GHG emissions data was generated using the eGRID methodology of combining region specific total output GHG emission rates with grid gross losses accounting for transmission and distribution line losses. Natural gas GHG emissions were not considered geographically specific and were therefore held constant across all locations as a combination of production GHG emissions from ecoinvent v3.4[38] and combustion GHG emissions from NREL's U.S. LCI Database[37]. The production GHG emissions system boundary encompasses manufacturing, pressurization and distribution, and losses such as flaring, venting and fugitive GHG emissions up to obtaining natural gas at a service station. Additional energy for delivery from service station to cannabis facilities was assumed negligible. All GHG emissions data from ecoinvent v3.4 and U.S. LCI were equated to CO_2-eq via methods outlined by the EPA's Tool for Reduction and Assessment of Chemicals and Other Environmental Impacts (TRACI) version v2.1[5], which uses the same 100-year global warming potential factors as the Intergovernmental Panel on Climate Change's Fourth Assessment Report[72].

Materials that required physical transport to the cultivation facility, and thus transportation GHG emissions accounting, included soil, fertilizers, fungicides, pesticides, and bottled CO_2. GHG emissions data for cradle-to-gate production and transportation was sourced from ecoinvent v3.4[38] and converted to

CO_2-eq via TRACI v2.1 methodology[5], see Appendix Tables B.8 and B.9. Distances from point of manufacturing to distribution centers, distribution centers to small retail, and small retail to cannabis grow facilities were modeled as 500 miles, 50 miles, and 10 miles, respectively for all locations. GHG emissions accounting for water was also cradle-to-gate, including the necessary pipeline infrastructure to be delivered to the cultivation facility. At the end of grow facility operations, several states that have legalized cannabis cultivation require disposal of all organic waste including the remaining plant portion that is not product, soils, and fertilizers. These waste products were modeled as transported to a municipal solid waste (MSW) landfill. Transportation of organic waste to the MSW landfill and heavy-equipment operations GHG emissions data were obtained from ecoinvent v3.4[38] whereas landfill organic decomposition GHG emissions were obtained from Morelli et al.[73] and Lee et al.[74].

One component of the GHG emissions assessment, carbon accounting, is worthy of further discussion to clarify the environmental burden assignment. The production of supplemental, bottled CO_2 stems from compressing and bottling a gaseous form to liquid form. The gaseous form of CO_2 exists as a necessary byproduct of ammonia production. As a result, it was assumed that without bottling, the CO_2 would be released to the atmosphere. Therefore, any CO_2 not utilized by the cannabis plants and released back to the atmosphere does not contribute a burden to the cannabis facility and is instead attributed to ammonia production that is outside the system boundary of this study. Thus, the only contributing GHG emissions from bottled CO_2 are a result of the upstream materials and energy needed to transform the CO_2 gas into a liquid and deliver it to the facility. A portion of the bottled CO_2 is considered to be stored by the plant product (dried flower) based on the assumed system boundary and the final carbon content of this biomass modeled as 48%[73]. The carbon associated with the remaining cannabis plant matter and soil that is transported to the MSW landfill was modeled as: 1) decomposing of organic material leading to methane (CH_4) and CO_2 generation or 2) non-degradable, or inert, carbon that is stored in the landfill. The CH_4 generated was modeled as either collected and combusted to form CO_2, oxidized to form CO_2, or released to the atmosphere as CH_4[74]. The collected and combusted and oxidized CH_4 streams were not counted toward GHG emissions as they are of biogenic origin and therefore balance with the carbon uptake from the plant biomass. The only GHG emissions contribution in the system boundary comes from the CH_4 portion of degradation that is not collected and was accounted for as having 25 times the radiative forcing than CO_2[72]. Stored CO_2 was accounted for as a negative GHG emission toward the overall GHG emissions from indoor cannabis production. Detailed carbon accounting can be found in Appendix Table B.10.

There are additional materials required to operate an indoor grow facility such as drip irrigation materials, plastic pots for various grow stages, cleaning supplies, latex gloves and masks for employees. It was determined that the amount of each material required to make a 1% contribution to overall GHG emissions would greatly exceed the amount of material that cannabis facilities could feasibly consume, and therefore these GHG emissions were omitted. The GHG emissions associated with construction of the indoor growth facility were not included as it was assumed that due to collocated grow and retail facilities, the warehouse would have been previously constructed and require minimal modifications. Additionally, the embodied GHG emissions associated with infrastructure materials were not included as they were assumed to be minimal over the operating lifetime of the indoor cannabis facility[75].

Cumulative GHG emissions were obtained for all 1,011 locations across the U.S. (see Appendix Table B.12) and serve as the foundation for the U.S. maps of Figure 3.1a. Location data and GHG emissions estimates were interpolated and displayed using Esri ArcGIS Pro v2.4. Values were interpolated using Kriging, with a spherical model and lag size of 25,000 m, and masked to the boundary of the U.S. GHG emissions values were interpolated two ways; first continuously throughout the U.S. and second masked to each eGRID region. The interpolated surfaces for each region were then mosaicked together for the entire U.S. All calculations were done with a cell size of 5,000 meters in the North America Albers Equal Area projection.

3.2.4 Model Validation

A baseline comparison of the foundational energetic loads was made by configuring the indoor cannabis model as a standard office building to compare energy requirements to those reported in literature. Configuring the model to a standard office building included changing lighting intensities, air exchanges and internal processes such as lowering heat from lights and removing humidity from plants while also adding heat from computers and occupants. Resulting energetic intensities, measured as energy use indices (EUI), yield a median value of 456 kWh per m^2 per year which can be compared to the value provided by Energy Star for commercial office buildings of 581 kWh per m^2 per year[76]. Modeling modifications were made to simulate a laboratory facility having ACH values closer to those found in indoor cannabis facilities. Resulting EUI values yielded a medium of 937 kWh per m^2 per year compared to the Energy Star median value of 1,004 kWh per m^2 per year[77]. These comparative energetic metrics identified that the foundational thermodynamic and heat transfer methodologies were accurate.

Further model comparisons were performed for the resulting energy intensities observed in literature. Results from a specific energy intensity, lighting, was observed to require 2,246 kWh per m^2 of growing space and was validated at 2,460 kWh per m^2 from model results[53]. In addition to lighting loads, comparison of overarching holistic values was performed through monthly electric bills, energy and GHG emissions of cannabis grow facilities. Electricity intensities from the indoor cannabis cultivation model ranged from \$35.96 to \$105.22 per grow cycle per m^2 of grow facility similar to what is reported in literature (\$15.50 to \$121.56 per grow cycle per m^2 of grow facility)[47,53,60]. As previously mentioned, some studies have done preliminary investigations analyzing the differences in energy and GHG emissions from growing cannabis indoors, in a greenhouse and outdoors[49,50]. Although these studies are limited in that the only source of energy considered was electricity, the results do provide a comparison metric. The range of electricity consumption for indoor production in the two reports is 1,270 to 6,100 kWh per kg of flower produced annually and results of this work range from 1,817 to 4,576 kWh per kg of flower produced annually[49,50]. Additionally, both reports provide values for GHG emissions from electric-based operations ranging between 562 and 3,000 kg CO_2-eq per kg of flower and results of this work range between 541 to 3,452 kg CO_2-eq per kg of flower produced annually. Mills[53] also reports 4,600 kg CO_2-eq per kg of final product, which is within the range observe in this study of 2,283 to 5,184 kg CO_2-eq per kg dried flower.

3.2.5 Limitations

We acknowledge that limitations and uncertainty exist within this body of work. Simplifications and assumptions were made primarily due to limited data availability and are most prevalent within the geographic considerations, transportation and system boundary. However, further refinement would likely lead to an increase in overall GHG emissions if modeling resolution improved, as all modeling inputs and assumptions were chosen to represent either average or conservative practice. The geographic resolution included in this analysis was limited to meteorological data and electric grid mix. However, the electric demand and variations in grid mix are the largest geographic discrepancy, and therefore improved resolution is expected to have minor impact on overall GHG emissions. Areas of the work that would benefit from improved geographic resolution are natural gas production and distribution and material transportation distances. The system boundary considered here is cradle-to-gate and ends at the point of finished cannabis flower. However, expansion of the system boundary to include transportation to retail, packaging, use and end-of-life would improve the findings of this work. Additionally, cannabis is manufactured into several products and each product supply chain would yield different GHG emissions results.

Preliminary work was performed to investigate uncertainty within the model including a sensitivity analysis as described previously. Results indicated that air exchanges, temperature and humidity ranges, and bottled CO_2 amount were the most sensitive variables to GHG emissions and therefore warrant particular attention when designing and optimizing individual indoor facilities.

CHAPTER 4: EXPANSION OF WATER SCARCITY FOOTPRINT METHODS FOR ARID REGIONS[c]

4.1. Background

The environmental impact of freshwater consumption is an essential component of life cycle assessment (LCA). Historically, traditional LCA methodologies, ISO 14040:2006 and ISO 14044: 2006, have excluded impacts from freshwater consumption as methods lagged in development. Recent standardization for water footprints (ISO 14046:2014) has led to an increased interest in method development that allows for characterizing freshwater consumption and its environmental impact. Specifically, the Available Water Remaining (AWARE) method, established by the Water Use in LCA (WULCA) Working Group, has been at the forefront of this development and become a well-recognized approach to characterizing freshwater impacts[78,79]. Despite these recent advancements in environmental impact methods for freshwater consumption, limitations in resolution remain, particularly for arid regions where the AWARE method truncates maximum impact factors.

The AWARE method is a consensus-based characterization model for determining environmental impact of freshwater consumption. Boulay et al. (2018) proposed this internationally supported method that determines a water scarcity footprint (WSF) by multiplying a volume of freshwater consumption with an appropriate water scarcity indicator, or characterization factor (CF). A WSF accounts for both the quantity and timing of freshwater consumption through the CFs by identifying water demand and availability in a specific region over a specific timeframe. Characterization factors are developed by comparing these spatially and temporally resolved water use values to a regional average, resulting in a unitless scalar that ranks the impact of freshwater consumption. The relative simplicity of determining a WSF should not be dismissed as a great level of complexity comes from the development of CFs. Boulay et al. (2018) originally developed CFs on a country basis, but recent work has indicated the need for

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improved resolution to some sub-national level[80]. In the United States, Argonne National Laboratory (ANL) recently published the highest geographically resolved CFs, allowing monthly and county-level assessments that account for substantial variations in freshwater supply and demand beyond the national level.[81,82]. Additional considerations have been discussed when attempting to improve resolution within CFs including weighting of AWARE CFs by water consumption type (industrial, domestic, livestock, for example) and aggregating CFs for product production[83].Although, the AWARE method has been accepted as the standard for WFS assessment, methodological limitations exist. Specifically, limitations exist within a cutoff method applied to CF development that leads to decreased resolution for arid regions.

The AWARE consensus-based method, known as Availability Minus Demand (AMD), has a cutoff criteria that does not allow CFs to go above a maximum value of 100 (1% of the regional average) or below a minimum value of 0.1 (10 times greater than the regional average)[78]. As a result of these cutoffs, several county and monthly CFs from the ANL dataset (U.S. specific) result at the maximum value of 100, most often occurring in arid regions[84]. For example, the American Southwest, specifically Arizona and New Mexico, show 38% of the total monthly- and county-level CFs resulted in the maximum value of 100. As a result, the determining capabilities of WSF for this region are limited. In the consensus-based process, Boulay et al. (2018) introduced a method, demand-to-availability (DTA), that was eliminated due to its inability to be broadly applicable to the majority of world[78]. As such, the method was not fully developed and abandoned in the consensus process. However, when using the consensus-based AMD method in arid regions, local decision-making for arid regions is shown to be limited due to the previously mentioned cutoff criteria. These limitations result in a lack of resolution in county-to-county CF and therefore county-to-county WSF.

It is critically important that we understand the impact of freshwater consumption in arid regions because, as in the case of the American Southwest, these regions can be agricultural hubs that demand substantial water amounts. Faced with persistent and increasing drought, regions such as the American

Southwest need the ability make decisions regarding freshwater use. Thus, the existing lack of resolution for these regions using the AWARE method warrants additional investigation and method expansion.

This work investigates a novel alternative CF development for arid regions when the AMD method lacks resolution due to methodological cutoffs. The DTA methods, originally suggested by Boulay et al. (2018) but not expanded upon, were developed in full and compared to results of the standard AMD approach. Lastly, a case study investigates crop production in Arizona and New Mexico highlighting the improved resolution and ability to identify unique stakeholder questions using the novel method.

4.2. Methods

This study investigated alternative CF development for assessing WSFs in arid regions. Results are compared to AWARE U.S. values that were previously developed using the AMD method[84]. It is necessary to first discuss the development of the baseline U.S. AWARE CFs to understand fundamentals for the proposed CF method.

4.2.1. Availability Minus Demand CF Development

A WSF determines the magnitude of the potential environmental impact from freshwater consumption for a product or process, as defined by ISO 14046:2014. A WSF is calculated by scaling the total freshwater consumption using CFs. The baseline water-stress CFs for this comparison study were developed by ANL (2020) for each U.S. county *i* and month *j.*

$$WSF_{i,j}(m3\ eq.per\ functional\ unit) = CF_{i,j} \times Water\ Consumption\ (m^3\ per\ functional\ unit) \quad \textbf{(4.1)}$$

Characterization factors are dimensionless scalars determined by a ratio of regional average, in this case U.S. average, water availability minus demand (AMD) to a specific U.S. county and month AMD, Eq. (4.2). The development of AWARE CFs has two interconnected limitations; 1) The cutoff values and 2) the method did not account for when demand is greater than availability, i.e. a negative $AMD_{i,j}$. The CF values are continuous with cutoffs applied to generate a maximum value of 100 when

$AMD_{i,j}$ is less than (including negative values) 1% of the average, annual U.S. AMD value, and a minimum value of 0.1, when $AMD_{i,j}$ is greater than 10 times the average U.S. AMD value[78].

$$CF_{i,j} = \frac{AMD_{U.S.}}{AMD_{i,j}} \tag{4.2}$$

These limitations result in a truncation of 7.2% of the U.S. month- and county-level CFs, with all truncations occurring at the maximum value of 100. No truncations were observed for minimum CF values of 0.1. Furthermore, most of the 7.2%, or 2,662, U.S. CFs are from arid regions, not surprisingly, because by design this cutoff occurs when demand is greater than availability. These occurrences are concentrated in what are defined as arid regions, or regions where limited rainfall or surface runoff are available. Therefore, the AMD method lacks necessary resolution for appropriate comparisons and decision-making within arid regions.

During the development of the AWARE methodology, alternative methods for determining CFs were proposed before consensus was reached on the AMD method, as previously outlined[78]. One of these methods was a ratio of demand to availability (DTA) but was eliminated during the consensus process due to the inability to answer their primary research question for a majority of locations around the world[78]. The primary research of Boulay et al. (2018) was aimed at developing a broad and universally applicable method for quantifying environmental impact from freshwater consumption around the world. Therefore, the DTA method was eliminated because it was deemed as an aridity index that was not broad enough to handle most of the world's land surfaces. However, 17% of the world's land surface does result with freshwater demands greater than availability[78]. Therefore, the DTA method should be further investigated for isolated studies occurring in these regions because the AMD method lacks resolution.

4.2.2 Demand to Availability CF Development

The DTA method was first presented by Boulay et al. (2015) and defined as an indicator that accounts for human and ecosystem demand with respect to availability. Following consistent nomenclature from ANL (2020) for a U.S. specific $AMD_{i,j}$, the $DTA_{i,j}$ ratio is defined here as:

$$DTA_{i,j} = \frac{Demand_{i,j}}{Availability_{i,j}} \tag{4.3}$$

Due to its early elimination in the consensus process, further development beyond introduction of the ratio was not established. As such, the methodological expansion and application of this ratio is developed and is presented here for primary use in arid regions because it accounts for situations where demand is greater than availability. The intent of expanding the DTA methodology is to improve sub-region resolution and clarity to arid region assessments in isolation. Considering the regionality of the DTA ratio, the CF relationship presented in Eq. (4.4) was established by comparing individual DTAs to a regional average DTA, Eq. (4.5). For example, the case study in this assessment (further discussed in sections 4.2.3 Comparison of DTA and AMD CFs and 4.2.4 Agricultural Case Study) focuses on the American Southwest, specifically Arizona and New Mexico, and therefore CFs and a corresponding $DTA_{AZ,NM}$ will be developed using data for the states' combined 48 counties. However, the DTA method presented can be adapted and developed for any geographical region. Monthly demand and availability data for all U.S. counties can be accessed from ANLs publicly available dataset[84].

$$CF_{i,j} = \frac{DTA_{i,j}}{DTA_{region\ average}} \tag{4.4}$$

$$DTA_{region\ average} = \frac{\sum\left(DTA_{i,j} \times HWC_{i,j}\right)}{HWC_{i,j}} \tag{4.5}$$

The regional average DTA value is in the denominator for the DTA method whereas it is in the numerator in the AMD method. This is necessary to keep numeric consistency with the AMD method in that higher CF values translate to a higher WSF, or more water deprivation potential. In physical meaning, a higher DTA CF results when higher individual location DTA ratios are above the regional average. This occurs when there is a proportionally larger demand to availability relative to the regional average demand to availability. Therefore, translating these situations to a higher, or worse, WSF is appropriate. Last, the regional average DTA of Eq. (4.5) is not a standard arithmetic average, but rather it is weighted by human water consumption (HWC) in consistency with method development of AMD

CFs[82]. This HWC for all months and U.S. counties and can be obtained from the open-source dataset provided by ANL[84].

4.2.2.1 Cutoff Criteria for DTA CFs

The AMD method from AWARE contains cutoff criteria generating upper and lower bounds for CFs. As previously described in 4.2.1 Availability Minus Demand CF Development, the CF cutoff yields a range between 0.1 and 100, Figure 4.1a. The maximum CF cutoff primarily avoids situations when AMD goes negative, or demand is greater than availability, and the minimum avoids situations where the AMD of a given region is much greater than the regional average. As previously mentioned, this results in a truncation of data for 7.2%, or 2,662, of the U.S. county-level CF values.

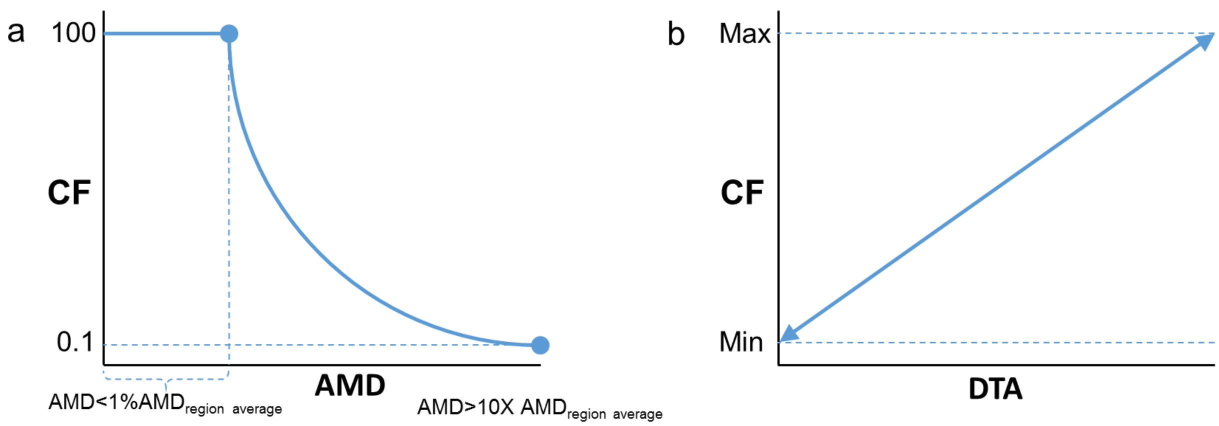

Figure 4.1*:Cutoff applications to CFs for AMD (a) and DTA (b) methods. The AMD method applies cutoffs resulting in a maximum value of 100 and minimum value of 0.1. The DTA method does not apply a cutoff and the numeric maximum and minimums are unique to the region of interest.*

One of the primary advantages and intents of the proposed DTA method is to account for occurrences when demand is greater than availability and therefore no cutoff criteria was proposed in this approach, Figure 4.1b. The linear correlation between CF and DTA are different than the exponential relationship observed with the AMD method. This is to be expected as the fundamental relationship for CF is different for two main reasons: 1) The fixed average value is in the numerator for the AMD method and in the denominator for the DTA method and 2) the individual DTA and AMD values that are compared to the average value are a difference of availability minus demand and a ratio of availability to demand, respectively. Mathematically, these fundamental differences result in different correlations.

4.2.3 *Comparison of DTA and AMD CFs*

The DTA methods are developed and presented here to better inform decisions when the limits of the AMD method are not achieved. Inherently, comparing DTA to AMD CFs is not recommended for future studies because the development of CFs is fundamentally different. However, the CFs from both methods are compared in this study for a discussion topic and presentation of results, primarily through the development of a case study.

To demonstrate the usefulness of this DTA method in arid regions, a case study was developed using monthly- and county-level demand and availability data from Arizona and New Mexico[82]. A region-specific average, $DTA_{AZ,NM}$, was determined to be 1.69 m^3 m^{-2} $month^{-1}$ using Eq. (4.5). Individual monthly- and county-level CFs were calculated using Eq. (4.4). For presentation of results, annual averages of the monthly CFs and were generated using Eq. (4.6), which is consistent with the development of annual AMD CFs[82].

$$CF_{i,annual\ average} = \frac{\sum DTA_{i,j}}{\sum\left(\frac{DTA_{i,j}}{CF_{i,j}}\right)} = \frac{\sum DTA_{i,j}}{12 \times DTA_{region\ average}} \tag{4.6}$$

4.2.4 *Agricultural Case Study*

The previous sections have focused on evaluating CFs and the corresponding results are discussed by evaluating county-level annual averages. However, CFs were determined on a monthly resolution and a complete WSF aggregates all monthly-level CFs, Eq. (4.1). Therefore, investigating completed WSFs can provide additional insight on methodological comparison between the AMD and DTA methods. Alfalfa is a primary crop for the Arizona and New Mexico region with more than 700,000 acres harvested between both states and was therefore selected for this case study. Two annual WSFs, AMD and DTA methods, were determined for each county in Arizona and New Mexico by summing monthly irrigation use weighted by characterization factors, Eq. (4.1). The CFs for the AMD method came from ANLs publicly available dataset[84]. The CFs for the DTA method were generated using Eq.

(4.4) and the monthly demand and availability values came the previously mentioned ANL dataset. Monthly irrigation data for alfalfa was obtained from the University of Arizona and equated to an annual crop use of 74.3 inches of irrigation[85].

4.2.4.1 Normalization of Results for Comparison

The numeric WSF results cannot be compared between AMD and DTA methods because they are fundamentally different. County-to-county comparison can be made for each method independently by comparing individual county WSFs to one another. Although these comparisons provided insight for each method independently, the magnitude of these ratios cannot be compared to one another as the magnitude of results are only relevant to each method independently. Therefore, a normalization was applied to the numeric results to compare the relative magnitudes. Each county-to-county comparison multiplier was normalized to the maximum possible multipliers (ratio of maximum WSF to minimum WSF from each method), using Eq. (4.7). This normalization removes any association with the magnitude of WSF and therefore allows for comparison of county-to-county impact across methods.

$$Normalized\ Ratio = \frac{\frac{WSF_{max}}{WSF_{min}}}{\frac{WSF_{county\ A}}{WSF_{county\ B}}} \tag{4.7}$$

4.3. Results and Discussion

The development and application of the DTA method is presented to improve upon previous limitations from the AWARE AMD method. Although not recommended in application, a direct comparison of the two methods is presented below to discuss capabilities and differences of each method. Last, a comparison is provided between WSFs of alfalfa in the desert southwest using both AMD and DTA methods.

4.3.1. Comparison of DTA and AMD CFs

The annual, county-level CFs from both the original AWARE AMD method and DTA method are presented in Figure 4.2. These CFs are not intended to be compared across methods numerically, meaning that a resulting CF from a particular county in the AWARE AMD method cannot be compared to a resulting CF from that same county in the DTA method. Rather, results are presented side-by-side here for comparison of the fundamental capabilities and intents.

In Figure 4.2a, several county CFs (38% of the regions counties) are at the AWARE AMD maximum cutoff value of 100 which ultimately limits resolution and deterministic capabilities. Results of the DTA method show a suite of CFs that enhance resolution, i.e. no cutoff method, and contain a singular maximum value, 3.3, and minimum value, 0.2. The primary intent of the DTA method is to better answer regionally specific questions with respect to WSF. With the increased resolution, counties can numerically be compared to one another where previous cutoff methods limited comparison. For example, in New Mexico, the AWARE AMD method showed that Curry, Roosevelt, Eddy and Dona Ana counties are all ranked as equally scarce from a freshwater consumption perspective in that their annual CFs were all 100. However, with the DTA method, Curry county is now shown to be 2.0, 4.9 and 5.9 times scarcer than Roosevelt, Eddy and Dona Ana counties, respectively. Using the DTA method for the Arizona and New Mexico region allows for increased resolution which will enable regionally specific decision-making.

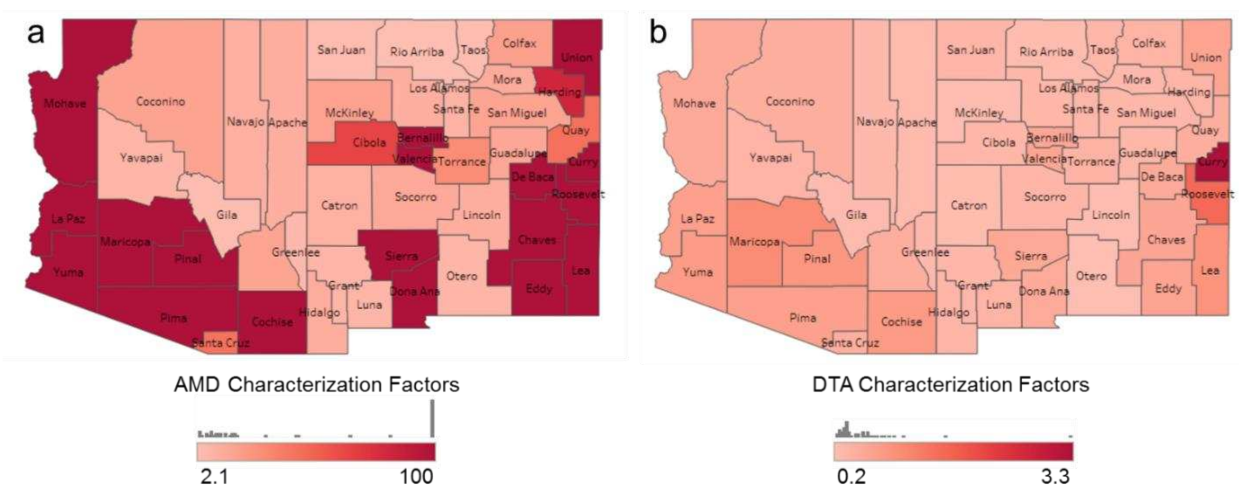

***Figure 4.2**: Annual average CFs for the (a) AWARE AMD and (b) DTA methods for AZ and NM. Characterization factors from the AWARE AMD method show 38% of counties at the maximum value of 100, as illustrated by the histogram above the color bar range (a). The DTA CF resolution show all counties on a continuous, non-truncated scale allowing for regionally relevant deterministic comparisons (b). The added resolution of the DTA results can be seen in the distribution of results occurrences shown by the histograms above each charts color bar. Results from each method are presented on their own numeric scale as the methods are fundamentally different.*

Results of Figure 4.2b visually appear to be minimized in intensity between the DTA CFs compared to those from the AWARE AMD method. This is mostly due to the lack of cutoff application in the methods which results in Curry, NM being an extreme thereby reducing relative impact of all other counties comparatively. Opposed to truncating Curry, NM by using a cutoff, or even outlier approach, the proposed DTA method numerically captures the true physical meaning here. The freshwater demand for Curry, NM is much greater than the availability which leads to a large numerator in determination of CFs, Eq. (4.4). Therefore, relative to Curry, NM and within the context of only Arizona and New Mexico, most other counties result in a low CF, hence the low visual saturation of Figure 4.2b. This regional comparison, however, does not imply that that all WSFs performed in this region will follow that same trend. The amount of water and timing for when it is consumed will play a role in calculating a WSF. These considerations and geographic variations in WSF are discussed in more depth in 4.3.2 Agricultural Case Study.

A large share, 94%, of CFs in the DTA method for this Arizona and New Mexico region are less than one. This means that evaluating a WSF using the CFs would lead to a lower WSF than the actual volume of water consumed. This finding is appropriate for the regionality of this case study however, because these arid regions are generally regarded as water scarce and therefore high impact on freshwater resources. The key component of this finding is that it is only true when analyzing Arizona and New Mexico in isolation. Ultimately, this finding occurs because Curry, NM is very water scarce, that it inflates the region average and devalues the remaining 47 counties. Although this finding is valid and holds true for this regional study, this further illustrates the inability to compare to U.S. counties outside this study. Furthermore, these results represent new insight to previously incomparable counties when using the AWARE AMD method.

4.3.2. Agricultural Case Study

A specific crop case study was investigated using complete WSFs to further illustrate the methodological differences and improved decision-making capabilities of the DTA method. Figure 4.3 shows a comparison of WSFs for alfalfa in Arizona and New Mexico from the AWARE AMD and DTA methods. Similar to the CFs, the numeric results are not intended to be compared across methods, rather the results of each can be compared independently. For example, the AWARE AMD method for alfalfa (Figure 4.3a) results in eight (La Paz, Pima, Pinal, and Yuma in Arizona and Chaves, Curry, Lea, and Union in New Mexico) of 48 counties for the region having a maximum and identical WSF (1,886,404 m^3-U.S.-eq per hectare). These identical results for the eight counties limit decision-making as no resolution exists between them. However, when using the DTA method, all eight counties result in different and unique WSFs allowing for comparison. From the DTA method, La Paz, Pima, Pinal, and Yuma counties in Arizona show WSFs of 14,556, 15,876, 18,502, and 15,379 m^3-AZ-NM-eq, respectively. In New Mexico, the DTA method results in Chaves, Curry, Lea, and Union counties having WSFs of 12,390, 79,772, 19,735, and 14,550 m^3-AZ-NM-eq, respectively. The added resolution of the DTA method for this region allows for understanding of how these counties compare to one another when producing alfalfa. These results now show that Curry, NM has a much higher WSF for alfalfa cultivation than the other seven counties that were all previously shown to have equivalent WSFs using the AWARE AMD method.

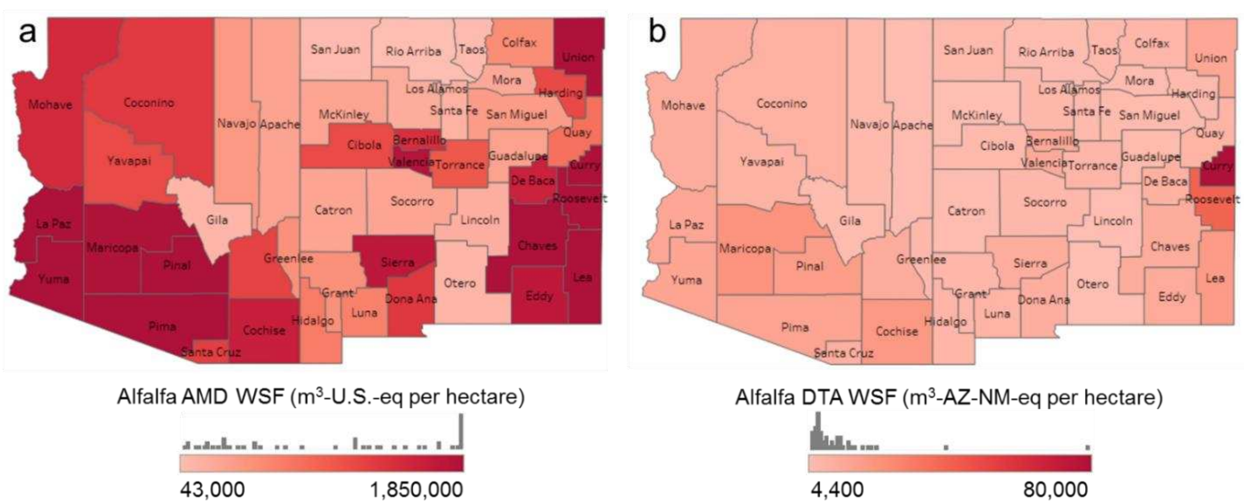

***Figure 4.3**: Water scarcity footprint of alfalfa using AWARE AMD (a) and DTA (b) methods. The AWARE AMD method results show eight of 48 counties with the same, maximum WSF whereas the DTA method shows full-scale resolution with no counties having identical WSFs. These WSF distributions for each method are represented by the histograms above each color bar. Results are shown on respective, independent scales with different units and are not meant to be numerically compared.*

4.3.2.1 Normalization Comparison

The relative comparison between counties for each method can also provide insight for decision making. Maricopa, Pinal and La Paz counties in Arizona and Curry, Roosevelt and San Juan counties in New Mexico are this region's largest alfalfa producing counties[86,87]. The AWARE AMD method shows that Chaves, NM has an alfalfa WSF that is 25 times higher than that of San Juan, NM whereas this comparison is 1.9 using the DTA method. This is effectively stating that when using the AWARE AMD method, growing alfalfa would lead to a much higher WSF than San Juan, NM while using the DTA method shows that this comparison is not has drastic. However, this comparison is not appropriate without removing the individual methods numeric magnitudes because they are fundamentally different. Thus, a normalization was applied to remove individual magnitudes which allows for comparison across methods, see 4.2.4.1 Normalization of Results for Comparison. Normalization is not necessary for standard DTA method use. Rather, it is applied here for discussion and ability to investigate capabilities between the AWARE AMD and DTA methods.

After normalization, the relative scale of multipliers from the AWARE AMD method is 1.7 and the DTA method is 9.5. This means that the AWARE AMD method shows that growing alfalfa in Chaves, NM is proportionally 1.7 times as intensive on water scarcity than growing in San Juan, NM whereas the DTA method shows that it is proportionally 9.5 times intensive. Therefore, the relative magnitude of each methods comparison shows that growing alfalfa in Chaves, NM is much worse when using the DTA method. This finding is more appropriate in this region, however, because cutoffs within the AWARE AMD method truncate the county-to-county comparisons thereby undervaluing relative scarcity impact. These findings further highlight the added resolution capabilities for county-to-county comparisons in arid regions when using the DTA method.

4.4. Limitations

The DTA method developed and presented here has limitations. As previously mentioned, the primary intent of the method is to regionally compare WSFs for arid regions where the AWARE AMD approach applies cutoff criteria which consequently limiting resolution. The presented DTA method, shown through application in Arizona and New Mexico, does increase resolution. However, it does not allow for an expanded comparison beyond the region of study. The method is designed to be used in isolation within the region under consideration and thus cannot be compared to results from either the AWARE AMD method or any other DTA evaluated region. This limitation holds true for both the CFs and WSFs across methods. As such, results from each unique DTA study are intended to be used solely for relevant and regionally decision-making.

Another limitation is the scope for which this method can be applied. The primary value of this method is increased resolution in regions where demand is greater than availability. Therefore, it is not recommended for evaluating other regions where most results have greater availability than demand. For example, evaluating the entire United States is not recommended because much of this region has more water availability than demand. Most often in these situations, individual county-level results would compare similarly to a few locations that have much greater demand than availability. These results would have a lack comparative resolution because most results would show low WSF compared to the few extreme counties. This approach would not provide very insightful results and thus it is recommended to use the AWARE AMD method when most counties have greater availability than demand.

Last, the developed DTA method is developed within the context of the AWARE methods and ultimately ISO: 14046:2014 and therefore encompasses any associated limitations from those methods. One primary limitation from these overarching methods is the limited scope in the grand scheme of water rights and related issues because they are performed independently. The resulting WSF from these methods are not intended to be an all-encompassing solution to water issues, but rather provided additional quantitative information on environmental impact from freshwater consumption and support comparative decision making. Both methods, AWARE AMD and DTA, do not actually quantify the water intensity of a process but rather the regional impact of freshwater consumption.

4.4 Conclusions

A novel method for evaluating WSF when previous limitations limited resolution and deterministic abilities is presented. The previous AWARE AMD method outlined cutoff criteria to occur when demand was greater than availability, which ultimately limited resolution for these areas. The DTA method was developed and no cutoff criteria was applied to the ratio such that all regionally specific data was evaluate. A case study was investigated in the arid Southwestern United States to understand the added value from the novel DTA method.

Results indicated that there was improved resolution and ranking between counties that were previously all determined to have a maximum WSF due to cutoff restrictions from the AWARE AMD methods. Although DTA results were not comparable to the AWARE AMD results in magnitude, relationships, and trends from the DTA results showed and increased ability for comparative assessment across all counties within the Southwestern United States. This improved resolution allowed for improved decision-making with respect to the region in isolation. Further investigation was performed through a crop case study investigating alfalfa. The alfalfa WSF comparison increased understanding of regional impact which, in combination with existing water policy and water law, can improve the freshwater environmental impact of the region.

Although this method does enhance resolution for regions when demand is greater than availability, inherent limitations remain. The primary limitations include the inability to numerically compare WSF between the AWARE AMD and DTA methods and the regional specificity which does not allow for comparisons outside the scope of each independent study. Despite these limitations, this method is advantageous for decision-making in regions where the AMD method lacks resolution from the use of cutoff criteria.

CHAPTER 5: OVERALL CONCLUSIONS AND FUTURE RESEARCH

5.1. Overall Conclusions

The three phases of research presented in this dissertation have identified and evaluated research gaps within agricultural systems. In the first phase, LCA and TEA methods were used to evaluate the sustainability of cultivating guar in the American Southwest. This phase generated economic and environmental feasibility results for a previously unknown agricultural pathway. Furthermore, the fundamentals of LCA and TEA were established allowing for expansion in subsequent research phases. In the second phase, LCA methods were used to investigate the commercial indoor cannabis industry. This phase allowed for advanced LCA applications including complex system boundary carbon accounting and geospatial resolution which resulted in understanding the GHGs from growing cannabis indoors around the U.S. These results provided a significant advancement in the cannabis research field and commercial industry allowing for industry improvements, consumer awareness, and policy development. In the third phase, a novel LCA method was developed that enhances the deterministic capabilities from water use. The work in this phase demonstrated the importance of regionality considerations, particularly in arid regions, when determining environmental impact from freshwater consumption. The introduced method provides increased resolution thereby enhancing decision-making capabilities for arid regions. The result of these three research phases has added and enhanced the understanding of sustainability within various agricultural systems and applications. Further research will provide additional insight into each of these three phases. The following three sections identify future research for each of the three phases evaluated in this dissertation.

5.2. Future Research on LCA and TEA of Guar

Results from the first research phase on guar use input parameters sourced from one experimental field trial in Las Cruces, New Mexico. This trial was focused on understanding irrigation and seed yield relationships. However, for critical parameters such as guar seed yield and endosperm content, the work could be greatly improved by incorporating additional field trial experiments that impact these primary input quantities. Several of these experiments are underway within the Sustainable Bioeconomy for Arid Regions (SBAR) project, but due to timing constraints and data collection limitations, only the irrigation study was incorporated. Incorporating field trial data from SBAR will allow for two key improvements to the first phase of work. First, the data will allow for understanding relationships between parameters such as irrigation, fertilizer, harvested seed yield, and endosperm content. Understanding these relationships will essentially generate a growth model which can improve agricultural scenario analysis and optimization for both economic and environmental impact results. Second, obtaining data from multiple field trial plots will allow the development of probability distributions for all input parameters. These distributions can serve as the foundation for stochastic modeling, such as Monte Carlo analysis, to develop probability distributions for economic and environmental impact results.

An additional area for future work within the guar gum supply chain is validation of the guar gum processing facility. Data used in the model was obtained from literature, patents, and some communication with the only U.S. processing facility in Brownfield, Texas. However, due to proprietary content restrictions, validation with an industry partner was limited. Therefore, a complete validation of this process would improve and enhance model validity. Furthermore, the model was evaluated for a small-scale, commercial facility and results are likely to change when evaluated for a larger facility. Therefore, the model and results could be improved by partnering with a large-scale production facility to understand minimum selling price and environmental impact of guar gum if full U.S. demand were to be met through domestic supply of guar. A large-scale facility does not currently exist in the U.S., but data could be obtained through partnering with companies in India which is the largest producer of guar gum in the world.

5.3. Future Research on LCA of Cannabis

The second research phase focused on using LCA to quantify the GHGs from indoor cannabis production across the U.S. Although the results represented a significant contribution to the research field, several limitations still exist. The primary limitations of the work include uncertainty and a constrained system boundary.

The indoor cannabis model was used to perform a sensitivity analysis which resulted in a suite of sensitive input parameters that warrant specific design considerations to reduce GHGs. However, a complete uncertainty analysis to understand the confidence within the results was not performed. This limitation was largely due to a lack of data for the input variables within the model. An uncertainty analysis can be done through partnering with multiple indoor cannabis cultivators to obtain enough data to generate probability distribution functions which can serve as the foundation for stochastic modeling, such as Monte Carlo analysis. Combining the previously performed sensitivity analysis with results from stochastic modeling would provide a full confidence profile of the model.

An additional limitation exists from the selection of the system boundary. The system boundary of the second research phase ends at the point of dried flower within the cultivation facility. Therefore, it does not include the downstream considerations of packaging, transportation to a retail facility, or waste. Furthermore, dried cannabis flower can be made into multiple products and therefore multiple downstream pathways could be investigated to understand the GHGs of various retail products like a joint, edible, or packaged flower. Obtaining data for these final products would require partnership with individual companies as minimal literature data exists. Furthermore, careful geospatial consideration would need to occur as states have unique processing, packaging, and waste regulations. The considerations of expanding system boundary and geospatial inclusions represent a large research opportunity that would provide valuable insight to the industry, consumers, and policymakers.

Last, the scope of Chapter 3 was limited to indoor cannabis production and does not include other major growth systems in the industry including greenhouse and outdoor. A significant research opportunity exists for understanding the system-level difference in GHGs from growing cannabis indoors, in a greenhouse, or outdoors. Furthermore, evaluating greenhouse and outdoor growth systems at a detailed process-level with geospatial resolution, similar to that of Chapter 3, would help identify and inform ways to reduce GHGs from those practices as well.

5.4. Future Research on Water Scarcity Footprint Methods within LCA

A novel method for evaluating WSF was presented in the third phase of research. This method was somewhat specific in that it applies primarily to arid regions where previous methods lacked resolution. The major limitation with this approach is that due to inherent changes in methods, results from the original method proposed by AWARE cannot be compared to results of the proposed method here. Further work investigating a universal method that can provide insight and full resolution for applications of freshwater consumption is needed.

Another limitation of both WSF methods is that they carry relevance only with respect to physical amounts of freshwater. Thus, results from any WSF are independent of water rights and therefore somewhat independent of reality. Therefore, results from WSF can be used to compare the impact of freshwater consumption if that actual amount of water could be consumed but does not say whether those water allocations are achievable in a given region. Therefore, results from WSF must be combined with water rights data to obtain the reality and impact of water use. One potential solution would be investigating a combined method that includes WSF methods and the current state of water rights and water allocation with spatial resolution. The combined information would be more useful for regional-level impact assessments whereas WSF is currently better suited for product development decisions.

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APPENDIX A

Table A.1. *Representative farm layout by crop and corresponding returns for the baseline scenario. A total of 245 farms were modeled in order to meet the demand throughput of the processing facility.*

Baseline Farm Layout		
CROP	% of farm	Hectares
Guar	15%	90.9
Cotton	5%	30.3
White Corn	5%	30.3
Sorghum	5%	30.3
Barley	5%	30.3
Wheat	5%	30.3
Wheat + Alfalfa Establishment	10%	60.6
Alfalfa Hay	50%	303.1
Total Baseline Farm	100%	600.0

Table A.2. *The average distances (kilometers) from field (farm) to process facility based on varying adoption rates of guar. The baseline scenario was built on the 14.9% adoption rate.*

Guar adoption rate (of farm)	14.3%	14.9%	15.6%	16.3%	17.0%	17.7%	18.3%	19.0%	19.7%	20.4%
average distance (km)	42.45	38.87	35.05	29.00	25.15	22.90	21.85	19.69	18.06	17.67

Table A.3. *Transportation modeling parameters for the baseline scenario. Calculations are based on the adoption scenario and values shown here correspond to 14.9% guar adoption.*

Variable Name	**Value**	**Unit**
Number of Trucks	13	
Cost of Truck	157,500	$/truck
Total Capital Cost	2,047,500	$ capital cost
Scenario Selected	14.9%	adoption
Average Distance	38.87	kilometers
Total Truck Weight	80,000	lbs
Truck Weight	20,000	lbs
Trailer Weight	15,000	lbs
Payload	45,000	lbs
Transport Weight	1.02	tonnes/ha
Total Transport Required	39.8	tonnes-km/ha
Fuel Efficiency	6.5	miles/gal
Fuel Consumption	0.37	gal/ha
Fuel Costs	1.01	$/ha
Truckloads needed	0.05	truckloads/ha
Number of trips	19.0	trips/day
Number of miles	917.7	miles/day
Average road speed	40.0	miles/hour
Average load/unload speed	12.36	acres/hour
Drive time per trip	1.21	hours/trip
Load time per trip	3.99	hours/trip
Total transport time	98.75	hours/day

Table A.4. *Detailed inputs for the downstream processing facility including material flow amounts and energy requirements. Process numbers correlate to those of Figure A.2.*

Process	Parameter Name	Value	Unit
200 - Extraction	Harvest Yield	0.41	tonnes/acre-yr
200 - Extraction	Residual Plant Matter (Bagasse)	9%	of harvest yield
200 - Extraction	Mass Loss Per Operation	0.3%	of input
200 - Extraction	Total Facility Mass Loss	5	% of input
200 - Extraction	Endosperm Fraction	32.5%	of input
200 - Extraction	Hull Fraction	27.5%	of input
200 - Extraction	Germ Fraction	40.0%	of input
200 - Extraction	Up-time days	350	days/year
200 - Extraction	Up-time shifts	2	shifts/day
200 - Extraction	Up-time hours	8	hours/shift
200 - Extraction	Processing Facility Size	5.00	acre
200 - Extraction	Office space	6,250	ft^2
200 - Extraction	Storage Volume	797,066	bushels per year
200 - Extraction	Processing Structure	250,000	ft^2
200 - Extraction	Air Conveyor Power	2.71	kWh/tonne
200 - Extraction	Shaker Table Power	0.30	kWh/tonne
200 - Extraction	Pneumatic Conveyor Power	1.375	kWh/tonne
200 - Extraction	Hammer Mill Power	10	kWh/tonne
200 - Extraction	Screw Conveyor Power	0.39	HP
200 - Extraction	Agitator Power	0.37	HP
200 - Extraction	Hopper Power	0.53	kWh/tonne
200 - Extraction	Polisher - Shaver Power	1.65	kWh/tonne
200 - Extraction	Heat Treatment Initial Moisture Content	13.5%	H_2O by %wt.
200 - Extraction	Heat Treatment Final Moisture Content	30%	H_2O by %wt.
200 - Extraction	Percent Water Absorption Efficiency	50%	H_2O by %wt.
200 - Extraction	Heat Treatment Water Supply	0.0170	tonne/min
200 - Extraction	Heat Treatment Water Heating Efficiency	0.80	MJ/MJ energy consumed
200 - Extraction	Heat Treatment Water Pump Power	1.12	kW
300 - Conversion	Spray Dryer Power	71.11	kWh/tonne
300 - Conversion	Hydration Bath Water Required	0.0216	tonne/min
300 - Conversion	Hydration Bath Water Pump Power	1.12	kW
300 - Conversion	Hydration Bath Initial Moisture Content	20%	H_2O by %wt.
300 - Conversion	Hydration Bath Final Moisture Content	45%	H_2O by %wt.
300 - Conversion	Steam Jet Power	5	kWh/tonne
300 - Conversion	Spray Dryer Final Moisture Content	11%	H_2O by %wt.
300 - Conversion	Shaker Table Power	0.30	kWh/tonne
500 - Conversion	Shaker Table Power	0.30	kWh/tonne
500 - Conversion	Pneumatic Conveyor Power	1.375	kWh/tonne
500 - Conversion	Hopper Power	0.53	kWh/tonne
700 - Conversion	Shaker Table Power	0.30	kWh/tonne
700 - Conversion	Pneumatic Conveyor Power	1.375	kWh/tonne
700 - Conversion	Hopper Power	0.53	kWh/tonne

Table A.5. *Annual guar crop budget from an irrigation-based experimental field plot. Budget represents breakeven cost and revenue of guar based on a 600-hectare farm (only 15% is guar, 90.9 hectares), full farm layout is provided in Table A1. Sections are organized as returns, non-harvest, harvest, and replacement costs.*

Returns	**Unit**	**$/Unit**	**Quantity/Unit**	**Value**
Guar	Kgs	$ 0.49	93,105.05	$ 45,795
Total Returns				**$ 45,795**

Harvest Inputs and Machine Costs	**Unit**	**$/Unit**	**Quantity/Unit**	**Value**
Combine (Custom)	Hectare	$ 61.87	90.92	5625
Interest on Harvest Operating Capital		$5,625.00	4%	$ 225
Total Harvest Costs				**$ 5,850**

Non-Harvest Production Inputs and Machine Costs	**Unit**	**$/Unit**	**Quantity/Unit**	**Value**
Guar Seed	Kgs	$1.65	816.47	$ 1,350
Fertilizer - N; Quantity	Kgs	$0.55	612.35	$ 338
Fertilizer - P; Quantity	Kgs	$0.46	2041.17	$ 945
Herbicides - Prowl; Quantity	Liters	$13.74	85.17	$ 1,170
Herbicides - Treflan; Quantity	Liters	$26.42	159.70	$ 4,219
Insecticides - Leverage; Quantity	Liters	$56.00	27.28	$ 1,528
Irrigation Water (Sprinkler)	m3	$ 0.05	216244.46	$ 10,519
Irrigation Labor (Sprinkler)	Hour	$ 13.13	168.75	$ 2,216
Irrigation, Sprinkler Repairs & Maintenance	Hectare	$ 49.49	90.92	$ 4,500
125 HP Tractor & Boom Sprayer (Repairs, maint., fuel & lube)	Hectare	$ 4.97	272.76	$ 1,356
125 HP Tractor & Boom Sprayer (Labor)	Hectare	$ 3.02	272.76	$ 825
175 HP Tractor & 18' Disc (Repairs, maint., fuel & lube)	Hectare	$ 11.17	90.92	$ 1,016
175 HP Tractor & 18' Disc (Labor)	Hectare	$ 4.61	90.92	$ 419
175 HP Tractor & Moldboard Plow (Repairs, maint., fuel & lube)	Hectare	$ 17.69	90.92	$ 1,608
175 HP Tractor & Moldboard Plow (Labor)	Hectare	$ 6.38	90.92	$ 580
125 HP Tractor & Drill (Repairs, maint., fuel & lube)	Hectare	$ 7.35	90.92	$ 668
125 HP Tractor & Fert. Sidedress (Repairs, maint., fuel & lube)	Hectare	$ 0.37	90.92	$ 34
125 HP Tractor & Drill (Labor)	Hectare	$ 4.46	90.92	$ 406
Other Expenses	Percent	5%		$ 1,685
Interest on Operating Capital		$ 35,455.08	4%	$ 1,415
Total Non-Harvest Costs				**$36,793**

Replacement Costs	**Unit**	**$/Unit**	**Quantity/Unit**	**Value**
Irrigation, Sprinklers	Hectare	$ 7.42	90.92	$ 675
125 HP Tractor & Fert. Sidedresser	Hectare	$ 1.01	90.92	$ 92
125 HP Tractor & Boom Sprayer	Hectare	$ 1.86	272.76	$ 508
175 HP Tractor & 18' Disc	Hectare	$ 9.98	90.92	$ 908
175 HP Tractor & Moldboard Plow	Hectare	$ 17.15	90.92	$ 1,560
125 HP Tractor & Drill	Hectare	$ 6.74	90.92	$ 613
Total Replacement Costs				**$ 4,356**

Total Annual Costs				**$ 46,999**

Table A.6. *Detailed processing economics for operation and capital expenditures. Process numbers correlate to those of Figure A.2.*

Process	Parameter Name	Value	Unit
200 - Extraction	Guar Seed Selling Price	484.82	$/tonne
200 - Extraction	Protein (Animal Feed) Selling Price	309.39	$/tonne
200 - Extraction	Manager	185397.87	$/yr-person
200 - Extraction	Engineer	88219.06	$/yr-person
200 - Extraction	Maintenance Supervisor	71907.72	$/yr-person
200 - Extraction	Maintenance Technician	50427.30	$/yr-person
200 - Extraction	Laboratory Manager	70644.17	$/yr-person
200 - Extraction	Laboratory Technician	50427.30	$/yr-person
200 - Extraction	Shift Operators	60535.73	$/yr-person
200 - Extraction	Yard Employees	35264.65	$/yr-person
200 - Extraction	Clerks or Secretary	45373.08	$/yr-person
200 - Extraction	Benefits/Overhead	0.90	$-benefit/$-salary
200 - Extraction	Plant Maintenance	3%	$-OpEx/$-CapEx
200 - Extraction	Insurance	1%	$-OpEx/$-CapEx
200 - Extraction	Heat Treatment Water Supply Pump	123.79	$/unit
200 - Extraction	Shaker Table	10377.80	$/unit
200 - Extraction	Steam Bath Screw Conveyor	67063.41	$/unit
200 - Extraction	Polisher - Shaver	2486.07	$/unit
200 - Extraction	Hammer Mill Required	20747.41	$/unit
200 - Extraction	Hammer Mill Required	17188.60	$/unit
200 - Extraction	Air Classifier	31192.76	$/unit
200 - Extraction	Pneumatic Conveyor	2845.79	$/unit
200 - Extraction	Pneumatic Conveyor	2835.55	$/unit
200 - Extraction	Pneumatic Conveyor	2079.51	$/unit
200 - Extraction	Pneumatic Conveyor	2349.17	$/unit
200 - Extraction	Air Conveyor Required	2823.08	$/unit
200 - Extraction	Land	2276.29	$/acre
200 - Extraction	Office Building	158.95	$/ft^2
200 - Extraction	Processing Structure	22	$/ft^2
200 - Extraction	Guar Seed Storage	3.35	$/bushel
200 - Extraction	Indirect Costs	89%	$/$
200 - Extraction	Contingency Costs	20%	$/$
300 - Conversion	Hydration Bath Water Supply Pump	143.03	$/unit
300 - Conversion	Hopper	43189.17	$/unit
300 - Conversion	Hydration Bath Mixing Tank	8938.85	$/unit
300 - Conversion	Agitator Required	2145.79	$/unit
300 - Conversion	Spray Dryer	263891.79	$/unit
300 - Conversion	Flaking Mill Required	14745.64	$/unit
300 - Conversion	Flaking Mill Required	14692.57	$/unit
300 - Conversion	Grinding Mill Required	14639.69	$/unit
300 - Conversion	Grinding Mill Required	14613.32	$/unit
300 - Conversion	Grinding Mill Required	14587.00	$/unit
300 - Conversion	Pneumatic Conveyor	1620.27	$/unit
300 - Conversion	Pneumatic Conveyor	2015.29	$/unit
300 - Conversion	Pneumatic Conveyor	2008.03	$/unit
300 - Conversion	Pneumatic Conveyor	1993.61	$/unit

300 - Conversion	Pneumatic Conveyor	1464.76	$/unit
300 - Conversion	Air Conveyor Required	1656.45	$/unit
500 - Conversion	Hopper	47987.97	$/unit
500 - Conversion	Polisher - Shaver	1728.58	$/unit
500 - Conversion	Pneumatic Conveyor	1627.51	$/unit
700 - Conversion	Hopper	43140.17	$/unit
700 - Conversion	Polisher - Shaver	1553.96	$/unit
700 - Conversion	Pneumatic Conveyor	1463.10	$/unit
All Processes	Electricity	0.0164	$/MJ
All Processes	Natural Gas	0.0051	$/MJ
All Processes	Industrial Water	0.13	$/tonne

Table A.7. *Equipment use accounting from the baseline scenario to inform cost share allocation (See Table A.8).*

	Guar	**Cotton**	**W. Corn**	**Sorghum**	**Barley**	**Wheat**	**Wheat+Alf Est**	**Alfalfa**
Hectares	90.9	30.3	30.3	30.3	30.3	30.3	60.6	303.1
Field Operations				**Passes/Hectare**				
Offset Disk	1	3	2	2	2	2	2	
Drag								1
Shank Chisel			2	2	1	1	1	
Moldboard Plow	1	1						0.2
Moldboard Plow + Drag								
Landplane								
Float, 14'		2						
4-Row Lister		1	1	1				
Bed Shaper		1						
8-Row Planter		1	1	1				
8-Row Cultivator		4	3	3				
Drill	1				1	1	1	
Cotton Picker, 4-Row		1						
Cotton Trailer, 8 Bale		1						
Shredder, 2 Row		1						
Combine			1	1	1	1	1	
Grain Cart			1	1	1	1	1	
Swather - Alfalfa Hay								5
Baler - Alfalfa Hay								5
Swather - Guayule								
Baler - Guayule								
Bale Wagon								5
Fert. Broadcast								1
Fert. Sidedress	1		1					
Boom Sprayer, 30'	3	1	1	1	1	1	1	2
Saddle Tank Sprayer			1					

Table A.8. *Economic breakdown for full farm equipment considering cost sharing for all crops*[88–91].

Machinery	Purchase Price	Budget Life (Years)	Labor ($/Acre)	Fuel ($/Acre)	Repairs ($/Acre)	Replacement ($/Acre)
175 HP 4WD Tractor	$180,000	15			$0.62	$2.88
125 HP 4WD Tractor	$80,000	10			$0.44	$0.62
V-Ripper	$22,000	10	$5.84	$10.05	$0.62	$2.88
Offset Disk	$30,000	15	$1.86	$3.20	$1.31	$4.03
Drag	$7,000	15	$2.19	$1.88	$0.72	$1.11
Shank Chisel	$17,000	15	$2.92	$5.02	$1.58	$4.35
Moldboard Plow	$35,000	15	$2.58	$4.43	$2.72	$6.93
Moldboard Plow + Drag	$35,000	15	$0.00	$0.00	$0.00	$0.00
Landplane	$18,000	15	$2.92	$5.02	$0.62	$2.88
Float, 14'	$7,000	15	$2.63	$2.27	$0.56	$3.06
4-Row Lister	$6,500	15	$3.72	$6.40	$0.86	$4.38
Bed Shaper	$6,500	20	$2.00	$3.44	$0.67	$6.27
8-Row Planter	$40,000	15	$1.67	$2.87	$1.14	$10.72
8-Row Cultivator	$22,000	10	$1.49	$1.28	$0.72	$2.69
Drill	$25,000	15	$1.80	$1.55	$1.42	$2.72
Cotton Picker, 4-Row	$75,000	10	$5.39	$13.90	$1.19	$75.38
Cotton Trailer, 8 Bale	$5,500	15	$14.44	$12.42	$1.38	$4.23
Shredder, 4 Row	$12,000	15	$3.34	$2.87	$0.89	$9.25
Combine	$180,000	10	$1.17	$3.26	$0.19	$29.90
Grain Cart	$18,000	15	$1.17	$2.01	$0.85	$4.61
Swather - Alfalfa Hay	$75,000	15	$1.59	$1.37	$3.06	$1.08
Baler - Alfalfa Hay	$120,000	10	$2.48	$2.13	$9.60	$2.92
Swather - Guayule	$75,000	7	$15.27	$13.14	$0.00	$0.00
Baler - Guayule	$120,000	5	$15.27	$13.14	$0.44	$0.62
Bale Wagon	$8,500	10	$2.48	$2.13	$0.71	$0.17
Fert. Broadcast	$18,000	20	$1.42	$1.22	$1.69	$1.51
Fert. Sidedress	$2,500	20	$0.00	N/A	$0.15	$0.41
Boom Sprayer, 30'	$9,500	20	$1.22	$1.05	$0.96	$0.75
Saddle Tank Sprayer	$3,500	20	$0.00	N/A	$0.14	$0.57

***Table A.9**. Life cycle inventory data from ecoinvent v3.4 used in the guar gum cradle-to-gate analysis*[38].

		Acidification	**Ecotoxicity**	**Eutrophication**	**Global Warming**	**Human Health - carcinogenics**	**Human Health - non-carcinogenics**	**Ozone Depletion**	**Photochemical ozone formation**	**Resource depletion - fossil fuels**	**Respiratory effects**
Process	**Functional Unit**	kg SO_2 eq	CTUe	kg N eq	kg CO_2 eq	CTUh	CTUh	kg CFC-11 eq	kg O3 eq	MJ surplus	kg PM2.5 eq
Diesel Production and Combustion	kg	4.9E-02	8.8E-01	4.5E-03	3.8E+00	1.7E-08	3.6E-08	9.1E-07	1.6E+00	7.6E+00	1.4E-03
Shed, construction	m^2	1.0E+00	2.6E+03	8.0E-01	3.3E+02	3.5E-05	1.1E-04	1.7E-05	1.5E+01	1.7E+02	1.8E-01
Tractor, production	kg	4.4E-02	9.7E+01	4.1E-02	8.2E+00	1.0E-06	4.6E-06	7.3E-07	3.7E-01	8.6E+00	8.8E-03
Agricultural Machinery, tillage, production	kg	3.1E-02	4.8E+01	2.5E-02	6.7E+00	1.1E-06	1.6E-06	3.6E-07	3.1E-01	3.6E+00	8.2E-03
Agricultural Machinery, unspecified, production	kg	2.6E-02	4.1E+01	2.3E-02	5.8E+00	9.4E-07	1.5E-06	3.4E-07	2.7E-01	3.5E+00	6.8E-03
Electricity supply	kWh	1.1E-03	2.8E+00	3.7E-03	4.9E-01	3.9E-08	1.1E-07	3.7E-08	1.6E-02	4.0E-01	1.4E-03
Harvester production	kg	4.0E-02	9.9E+01	3.8E-02	6.9E+00	1.1E-06	4.6E-06	4.3E-07	3.4E-01	5.1E+00	8.3E-03
Polyethylene production, high density, granulate	kg	6.4E-03	1.2E+00	4.8E-04	1.9E+00	6.2E-08	2.4E-08	1.2E-09	8.1E-02	9.5E+00	4.4E-04
Extrusion plastic film production	kg	3.0E-03	2.2E+00	2.3E-03	7.0E-01	3.5E-08	9.9E-08	3.7E-08	3.4E-02	5.1E-01	9.1E-04
Excavation hydraulic digger production	m^3	5.1E-03	7.3E-01	7.1E-04	5.4E-01	2.4E-08	2.3E-08	1.3E-07	1.5E-01	1.1E+00	7.1E-04
Cast iron production	kg	8.0E-03	3.4E+01	5.7E-03	1.8E+00	2.8E-06	3.7E-07	1.2E-07	1.0E-01	1.0E+00	2.4E-03
Polyvinylchloride production	kg	6.1E-03	2.9E+00	1.2E-03	2.1E+00	1.3E-07	6.9E-08	1.9E-08	1.1E-01	6.1E+00	3.9E-04
Processing Water Supply	kg	1.1E-06	8.1E-04	8.9E-07	2.6E-04	1.4E-11	3.8E-11	1.5E-11	1.3E-05	1.6E-04	3.7E-07
Natural Gas Production and Combustion	kg	4.3E-03	1.4E+00	1.0E-03	3.1E+00	2.0E-08	4.7E-08	3.7E-07	7.9E-02	7.3E+00	4.2E-04
P - Fertilizer	kg	2.1E-02	2.2E+01	2.7E-02	1.9E+00	1.4E-07	1.2E-06	2.3E-07	1.5E-01	3.2E+00	3.6E-03
N - Fertilizer	kg	1.8E-02	1.2E+01	5.9E-03	3.3E+00	9.3E-08	5.6E-07	5.8E-07	1.1E-01	7.5E+00	3.0E-03
Trailer Production	kg	4.2E-02	4.3E+01	2.7E-02	8.0E+00	1.4E-06	1.8E-06	4.2E-07	4.0E-01	4.7E+00	8.7E-03
Ammonium Nitrate Production	kg	3.7E-02	2.6E+01	1.7E-02	8.8E+00	1.5E-07	1.2E-06	5.8E-07	3.9E-01	7.1E+00	3.4E-03
Transport by Truck	ton-km	4.6E-04	0.0E+00	2.9E-05	9.1E-02	0.0E+00	0.0E+00	0.0E+00	1.6E-02	0.0E+00	3.9E-05
Clethodim (cyclohexanone)	per kg	2.1E-02	3.9E+01	1.4E-02	4.7E+00	2.0E-07	1.4E-06	3.0E-07	2.1E-01	9.5E+00	3.9E-03
2,4, DB Production	per kg	1.9E-02	2.5E+01	1.9E-02	4.5E+00	2.5E-07	9.6E-07	1.2E-06	2.6E-01	7.4E+00	4.8E-03
Treflan (2-nitroaniline) production	per kg	3.0E-02	6.3E+01	4.8E-02	7.0E+00	3.2E-07	1.3E-06	1.2E-06	3.2E-01	1.0E+01	5.5E-03

Brawl (pendimethalin) production	per kg	2.3E-02	1.7E+01	1.9E-02	5.9E+00	1.6E-07	8.0E-07	3.1E-07	2.5E-01	9.5E+00	2.7E-03
Soybean Production	per kg	1.5E-03	9.3E-01	9.6E-04	4.1E-01	8.0E-09	3.4E-08	3.1E-08	3.0E-02	2.1E-01	2.1E-04
Soybean Meal and Crude Oil Production, soybean meal	per kg	1.6E-03	1.0E+00	1.1E-03	4.3E-01	1.1E-08	3.9E-08	3.2E-08	2.9E-02	2.6E-01	2.9E-04

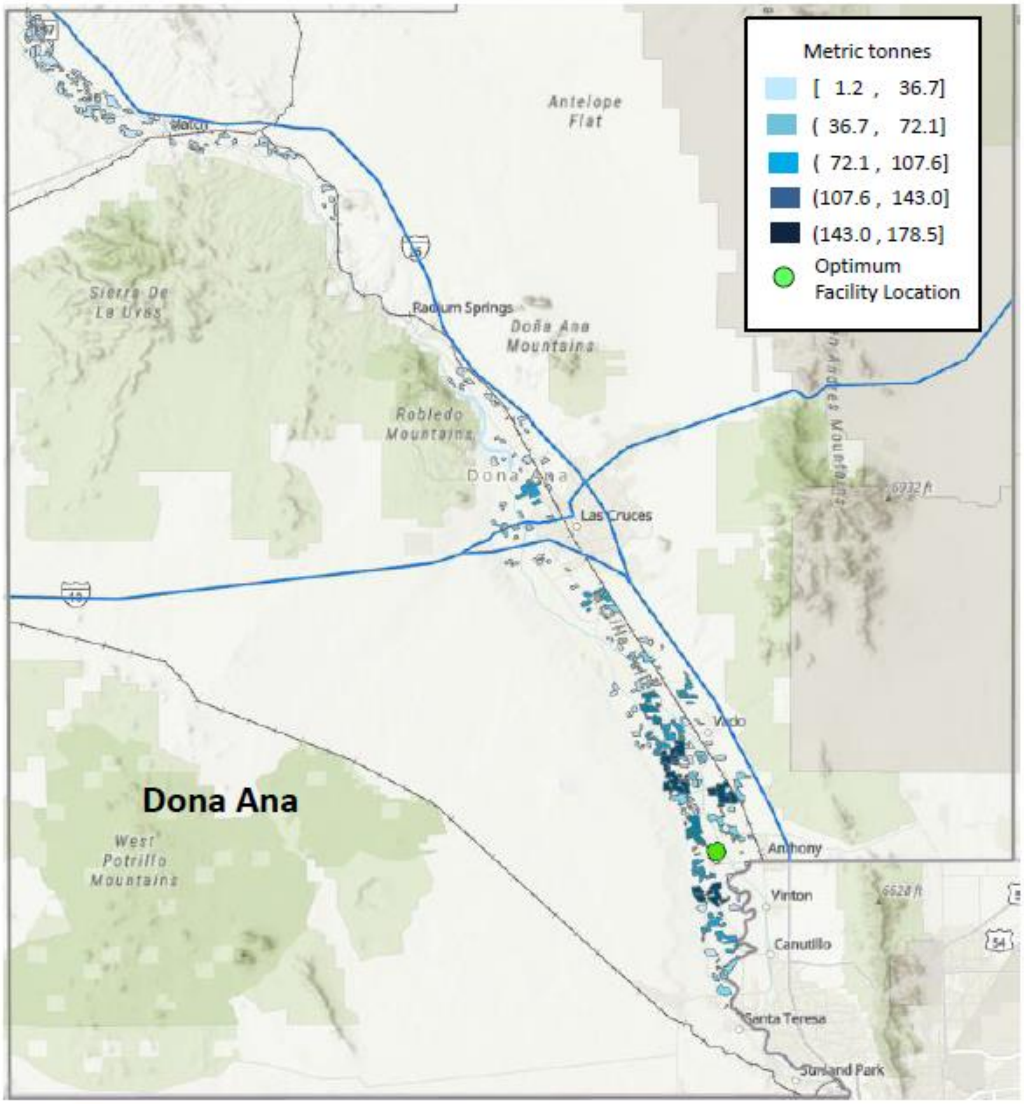


Figure A.1. *Results of transportation optimization model for guar*[19]*. Shown are expected guar productivity from Dona Ana County's cotton, grains, and oilseeds (CGO) group farms and a resulting optimal location for a hypothetical guar bean processing facility [(Latitude, Longitude) = (32.0093699, -106.6491657)]. Transportation distances were determined by %crop adoption (Table S2) with respect to the processing facility location.*

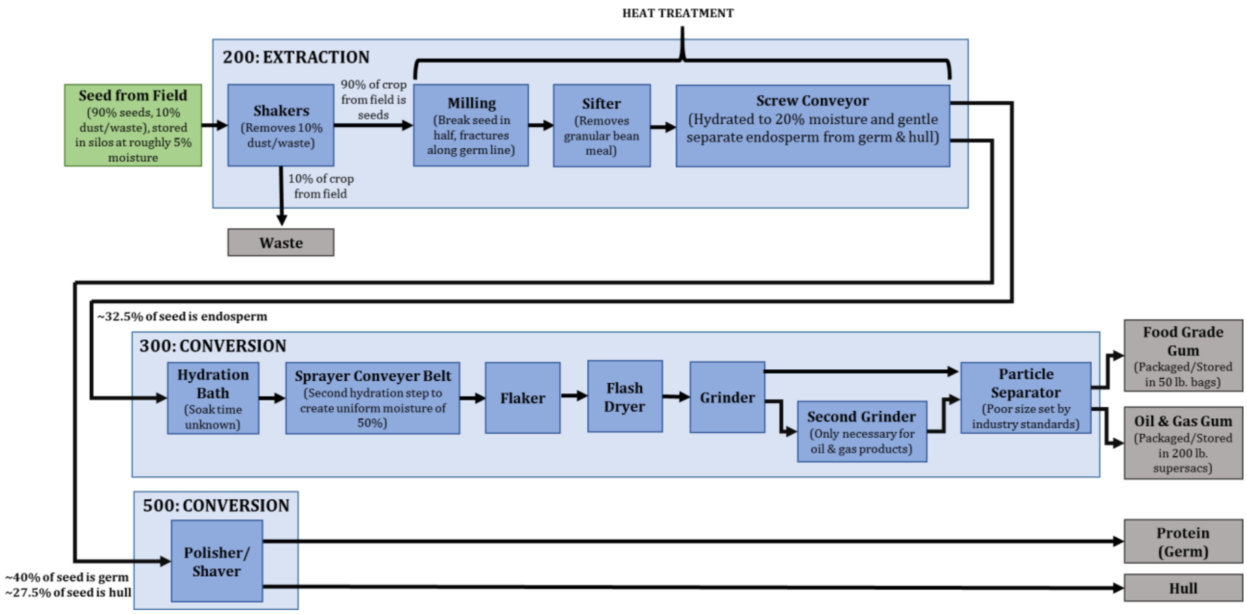


Figure A.2. *Process flow diagram for processing guar to guar gum.*

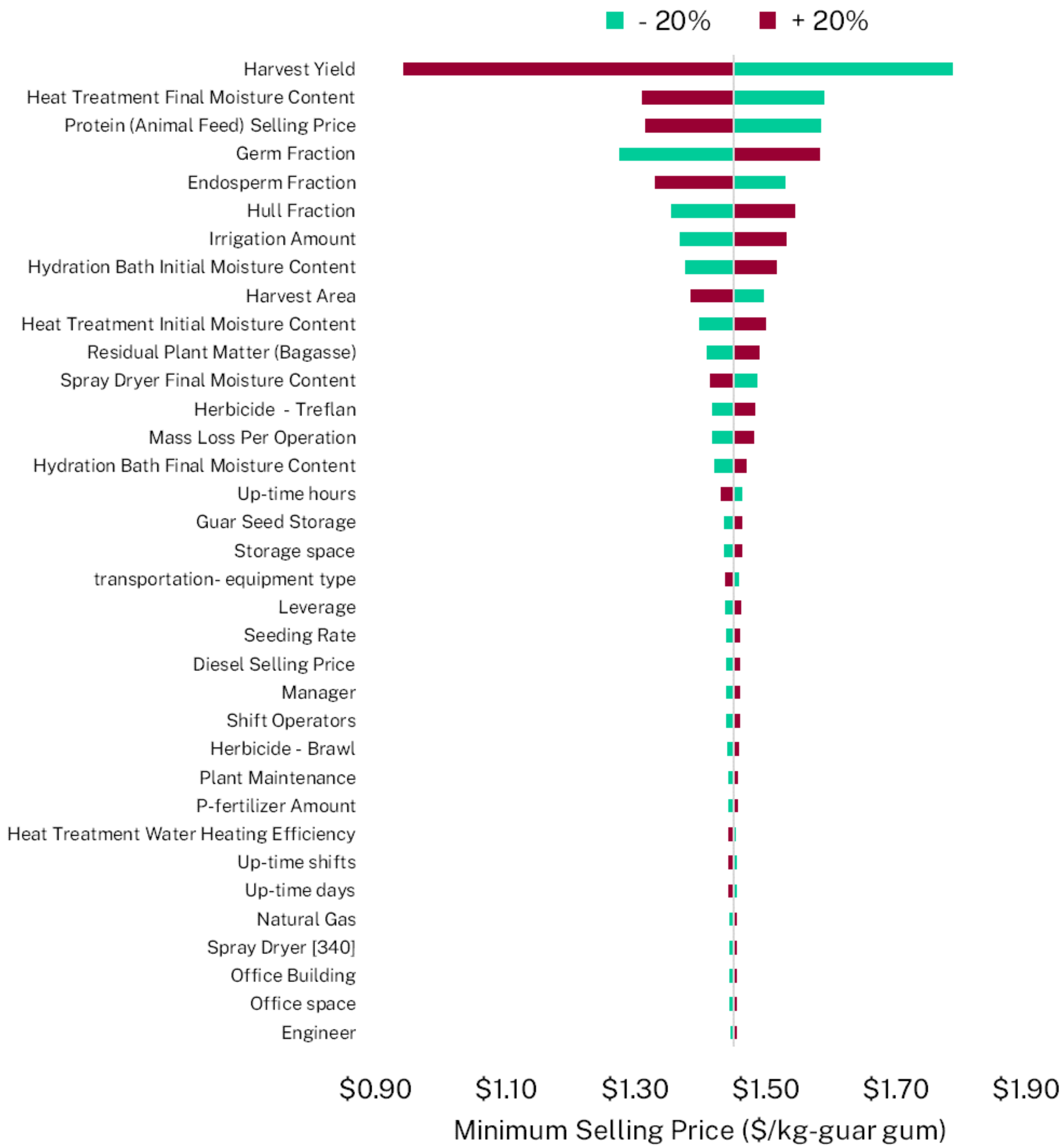
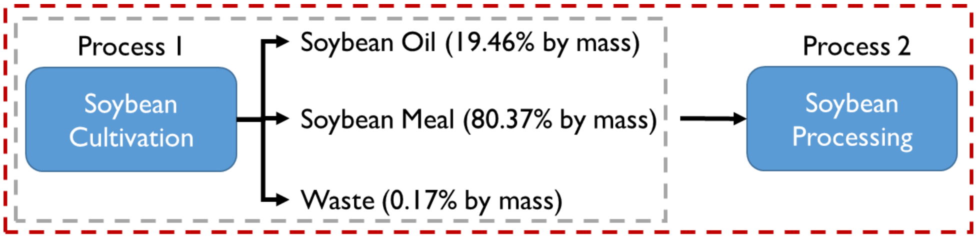


Figure A.3 *Full sensitivity analysis showing economic response when arranging all input parameters by ±20%. Only parameters that resulted in an impact larger than $0.01 per kg-guar gum, either positively or negatively, are shown.*



$$Soybean\ Meal\ Displacement\ Emissions\ (per\ kg\ meal) = (Process\ 1 \times 80.37\%) + Process\ 2$$

Figure A.4. *Displacement emissions allocation for guar meal based on soybean meal processes (see Table A7 for emissions values). Soybean Cultivation provided emissions per kg soybean and was thus mass allocated to only soybean meal. These allocated emissions were added to the emissions of processing soybean meal to get cradle-to-gate emissions per kg soybean meal.*

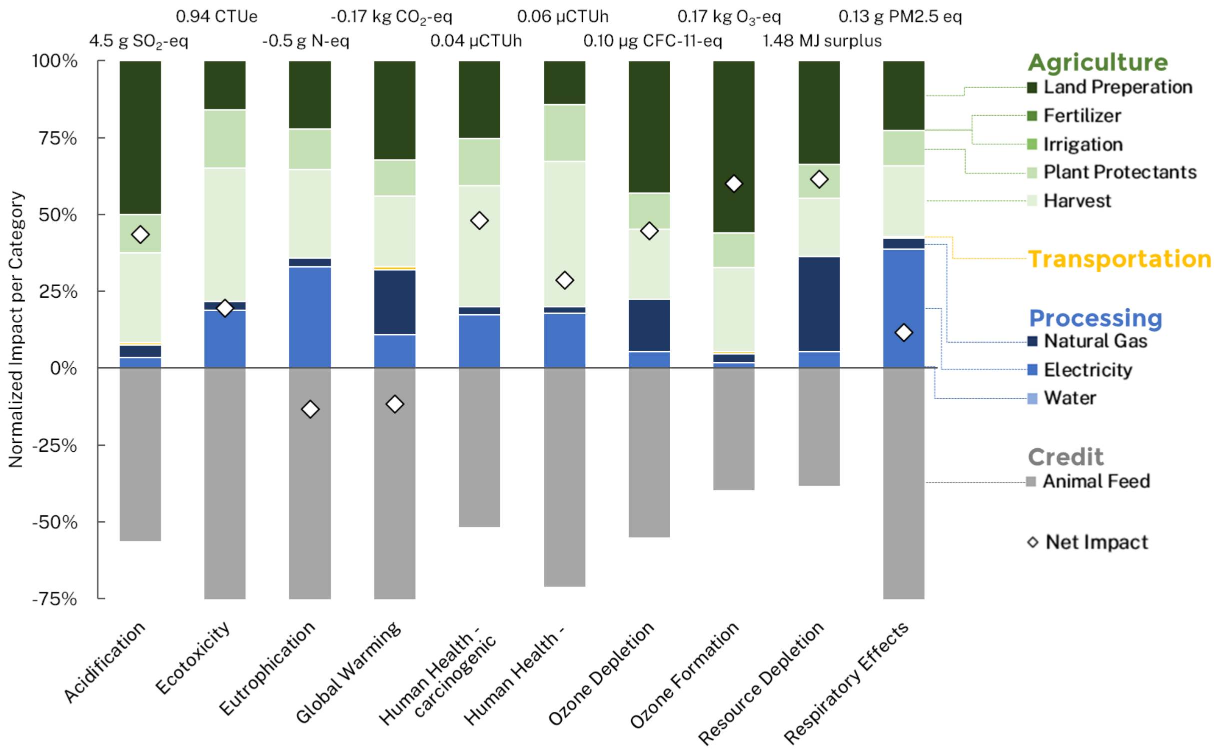


Figure A.5*. Environmental impacts of the best case scenario per kg-guar gum produced, aggregated in TRACI categories. Total values presented at the top of the figure represent net emissions, including animal feed displacement credit. from the modeled baseline scenario. Results include agriculture (green), transportation (yellow), downstream processing (blue) and animal feed coproduct displacement credit (grey).*

Appendix A References

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APPENDIX B

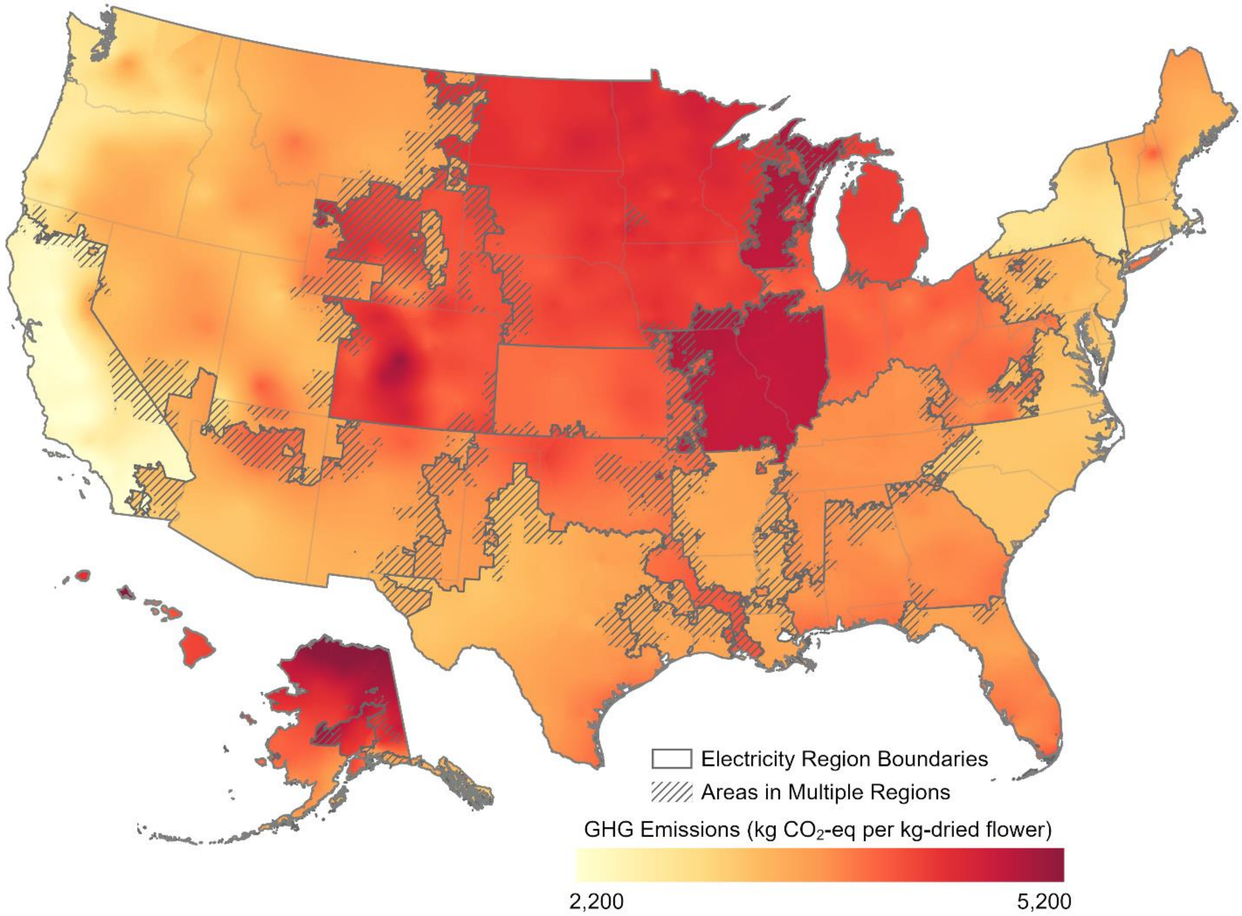

Figure B.1: *Cumulative GHG emissions of cultivating cannabis indoors interpolated within eGRID electricity region boundaries (kg CO_2-eq per kg-dried flower). This figure is panel a of Figure 1 in the main manuscript.*

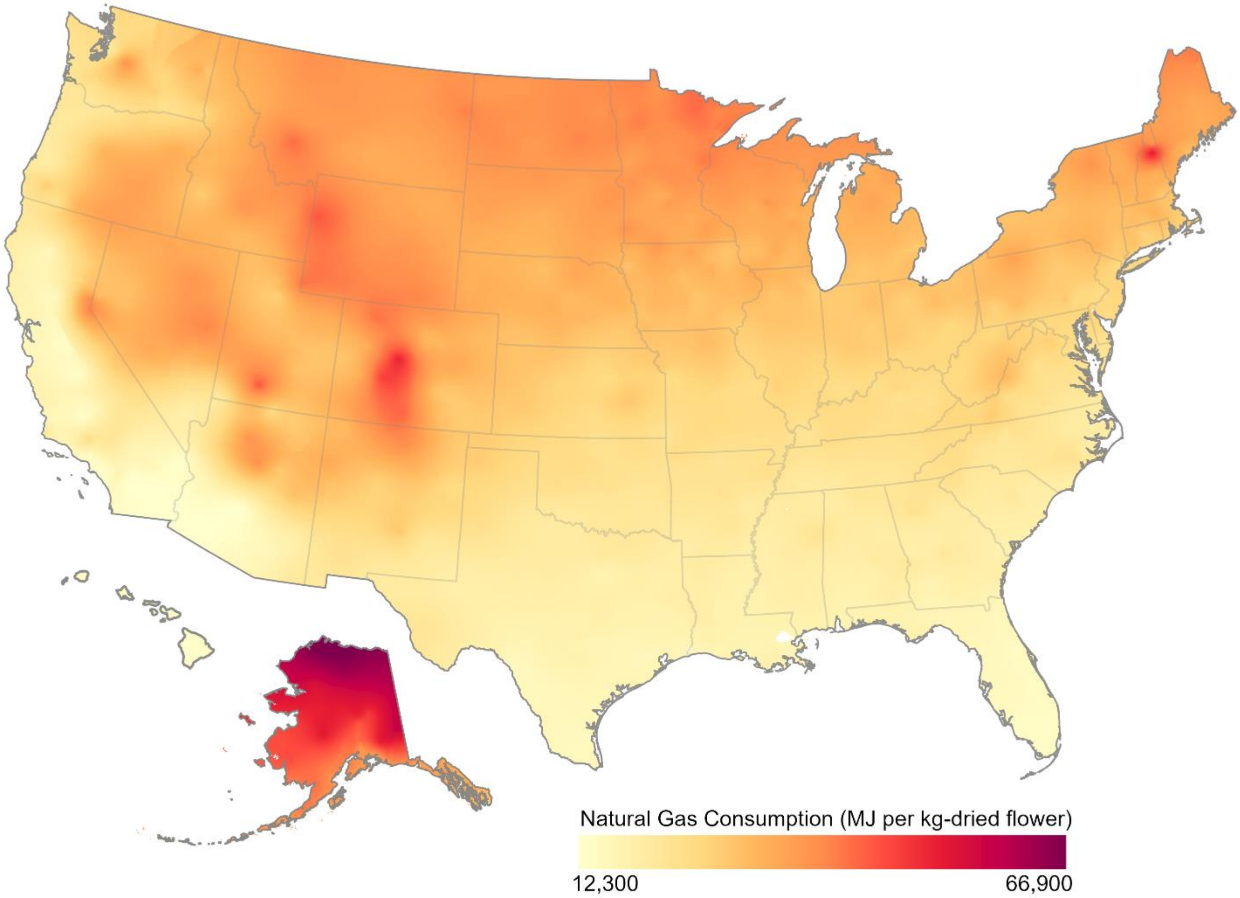

Figure B.2: *Natural gas required for indoor cannabis production across the U.S. (MJ per kg-dried flower). Natural gas is necessary to maintain indoor environmental conditions. This figure is panel b of Figure 1 in the main manuscript.*

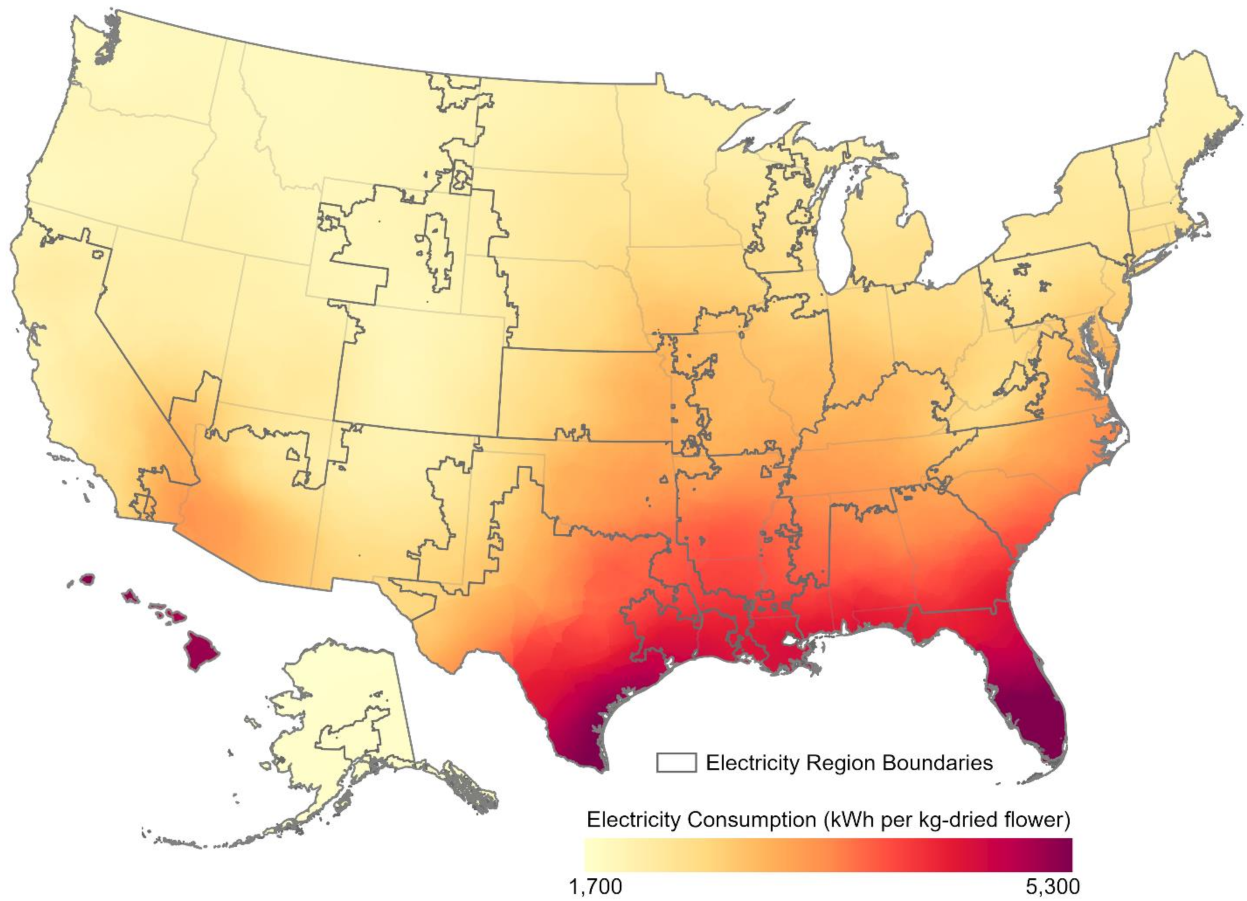

Figure B.3: *Electricity required for indoor cannabis production across the U.S. (MJ per kg-dried flower). Electricity is necessary to maintain indoor environmental conditions and supply high-intensity grow lights. This figure is panel c of Figure 1 in the main manuscript.*

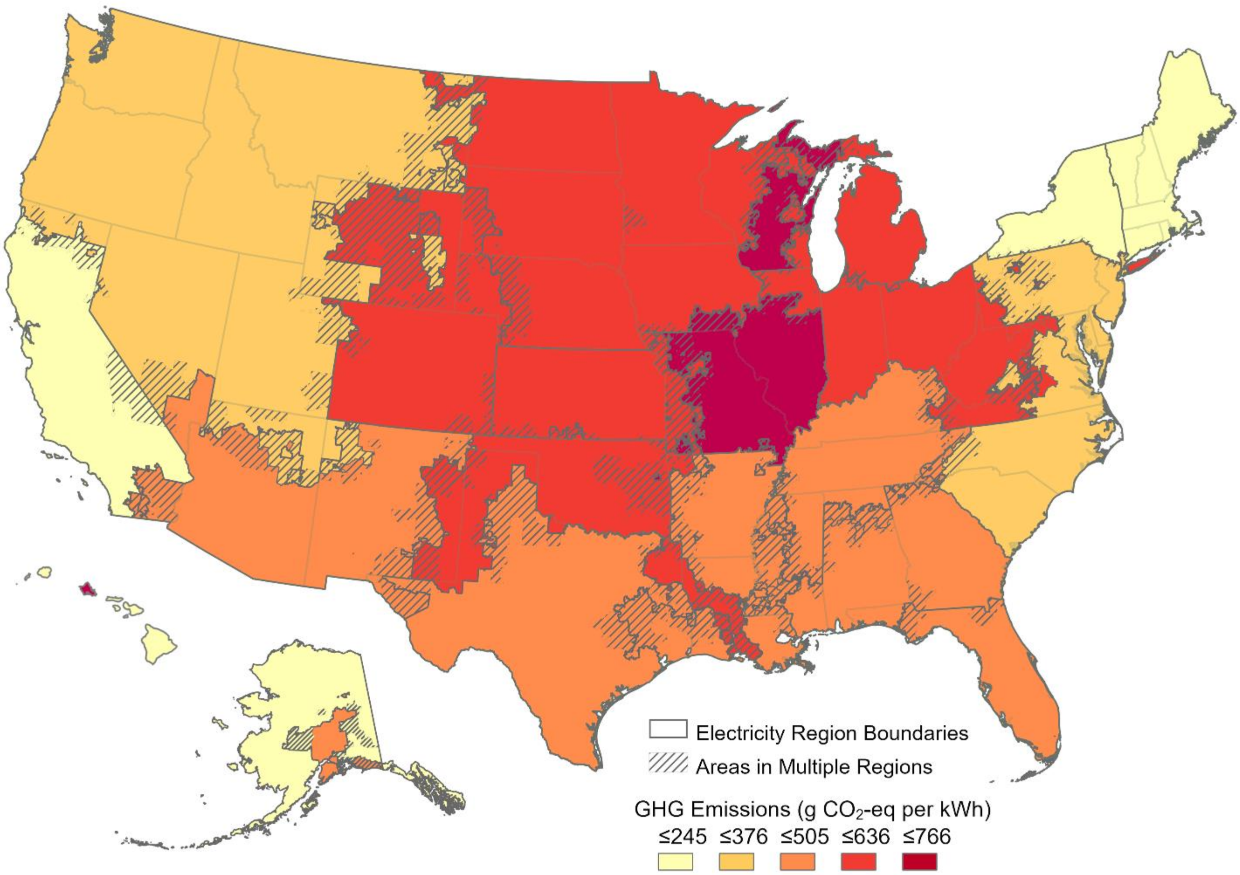

Figure B.4: *GHG emissions intensity for the 26 U.S. regions provided by U.S. EPA's eGRID (kg CO_2-eq per kWh). This figure is panel d of Figure 1 in the main manuscript.*


Long Beach, CA
+20
-20%
Plant Yield (kg-flower/plant)
Air Changes Per Hour
CO_2 Concentrations (ppm)
Lighting Intensity (W/m²)
Humidity Range
Temperature Range
1800 2600 3400 4200 5000 5800 6600
GHG Emissions (kg CO_2-eq per kg-dried flower)
Seattle, WA
+20
-20%
Plant Yield (kg-flower/plant)
Air Changes Per Hour
CO_2 Concentrations (ppm)
Lighting Intensity (W/m²)
Humidity Range
Temperature Range
1800 2600 3400 4200 5000 5800 6600
GHG Emissions (kg CO_2-eq per kg-dried flower)
New York, NY
+20
-20%
Plant Yield (kg-flower/plant)
Air Changes Per Hour
CO_2 Concentrations (ppm)
Lighting Intensity (W/m²)
Humidity Range
Temperature Range
1800 2600 3400 4200 5000 5800 6600
GHG Emissions (kg CO_2-eq per kg-dried flower)
Phoenix, AZ
+20
-20%
Plant Yield (kg-flower/plant)
Air Changes Per Hour
CO_2 Concentrations (ppm)
Lighting Intensity (W/m²)
Humidity Range
Temperature Range
1800 2600 3400 4200 5000 5800 6600
GHG Emissions (kg CO_2-eq per kg-dried flower)
Jacksonville, FL
+20
-20%
Plant Yield (kg-flower/plant)
Air Changes Per Hour
CO_2 Concentrations (ppm)
Lighting Intensity (W/m²)
Humidity Range
Temperature Range
1800 2600 3400 4200 5000 5800 6600
GHG Emissions (kg CO_2-eq per kg-dried flower)
Chicago, IL
+20
-20%
Plant Yield (kg-flower/plant)
Air Changes Per Hour
CO_2 Concentrations (ppm)
Lighting Intensity (W/m²)
Humidity Range
Temperature Range
1800 2600 3400 4200 5000 5800 6600
GHG Emissions (kg CO_2-eq per kg-dried flower)

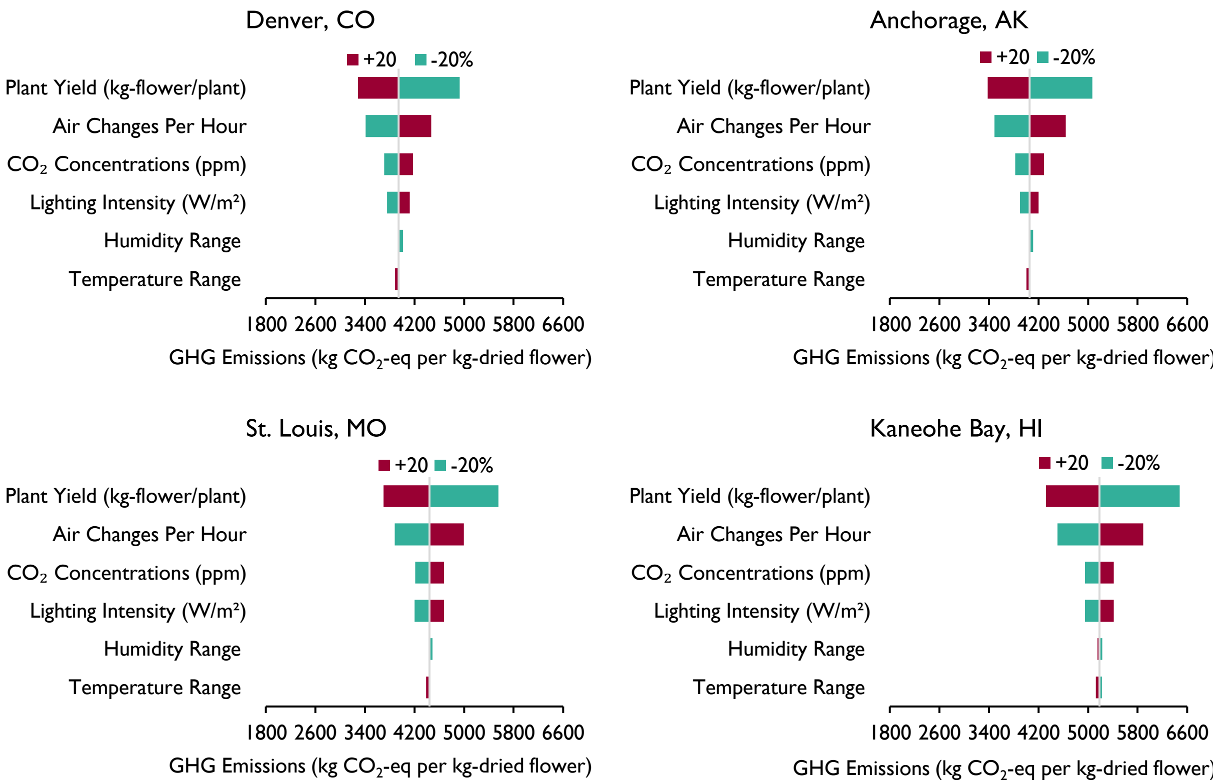

Figure B.5: *Results from the sensitivity analysis showing the top 6 sensitive variables for the ten geographically varying locations of Figure 2. Descriptions of variable changes are provided below the figure. All variables and ranges, described below, were changed from their baseline modeled value to gauge response to GHG emissions. Ranging plant yield means changing the amount of dried flower obtained per plant by +/- 20%. Air changes per hour were varied +/- 20% for HVAC operations.* CO_2 *concentrations were varied +/-20% for both vegetation and flower rooms. Lighting intensities were varied +/-20% for clone, vegetative and flower rooms simultaneously. All humidity values, high and low depending on lighting loads and stage of growth, were varied by expanding or contracting allowed set point targets (shown in Supplemental Figure 9) by +/- 20%. All temperature, high and low depending on lighting loads and stage of growth, were varied by expanding or contracting allowed set point targets (shown in Supplemental Figure 9) by +/-20%.*

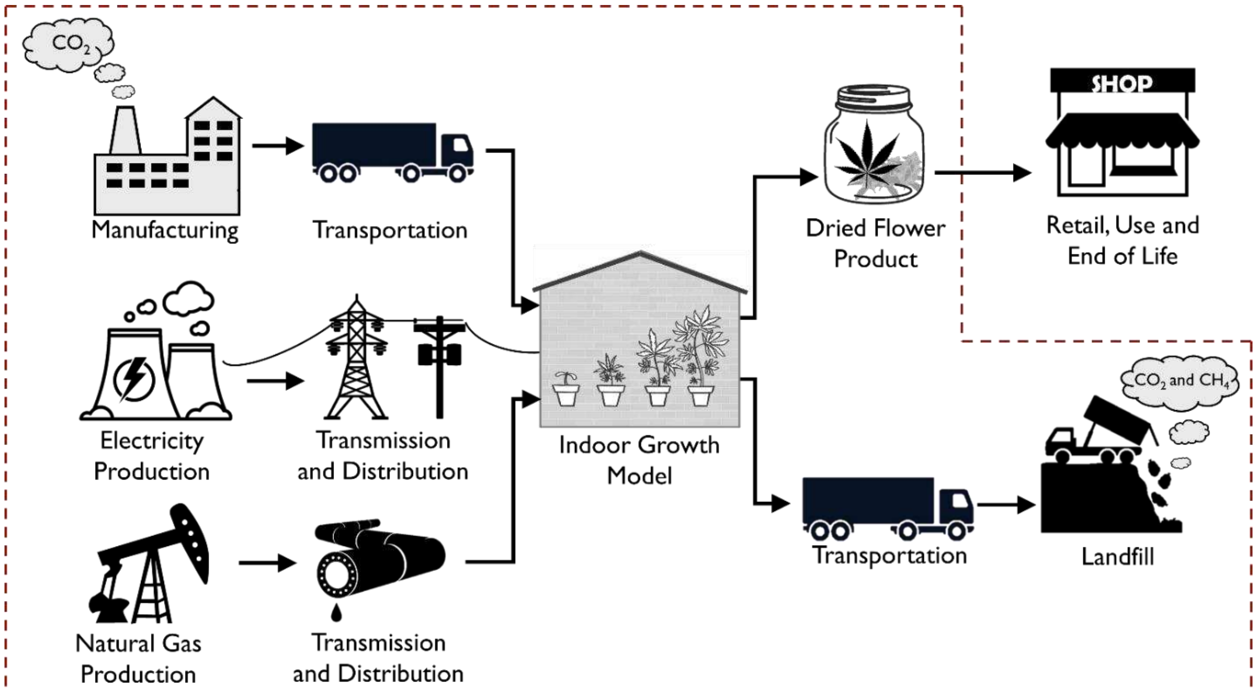

Figure B.6*: Process flow diagram of the cradle-to-gate system boundary for the modeling of indoor cannibus prodcution in this study. To determine the GHGs from indoor cannabis production at all U.S. locations analyzed, upstream emissions from manufacturing and transportation of all material inputs was included along with production and transmission and distribution of all energy related emissions. Additionally, downstream emissions from transporting waste to a municipal solid waste landfill and the degradation of material in the landfill were included in the system boundary (red dashed line). All emissions were allocated to the dried cannabis flower as it is the only product from the system. Additional information on quantities of inputs can be found in Appendix Table B.5 and corresponding life cycle inventory processes used from ecoinvent v3.4 and U.S. LCI can be found in Appendix Table B.9.*

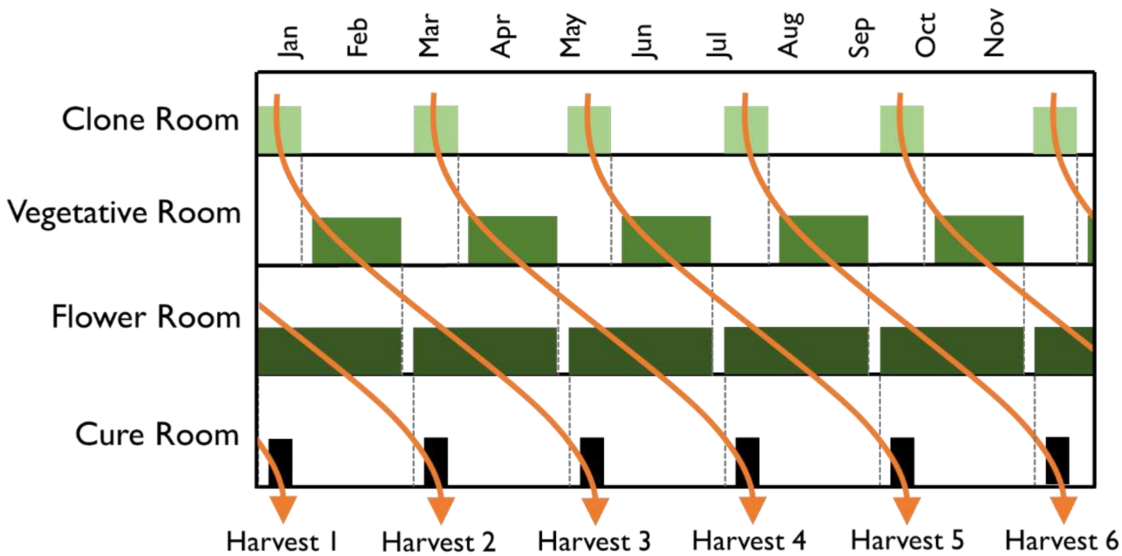

Figure B.7: *Cannabis facility layout illustrating the various plant stages of growth modeled and rotated through the building. Each room was modeled with capabilities illustrated in Supplemental Figure 8. Continual operation was modeled achieving 6.2 harvest per year.*

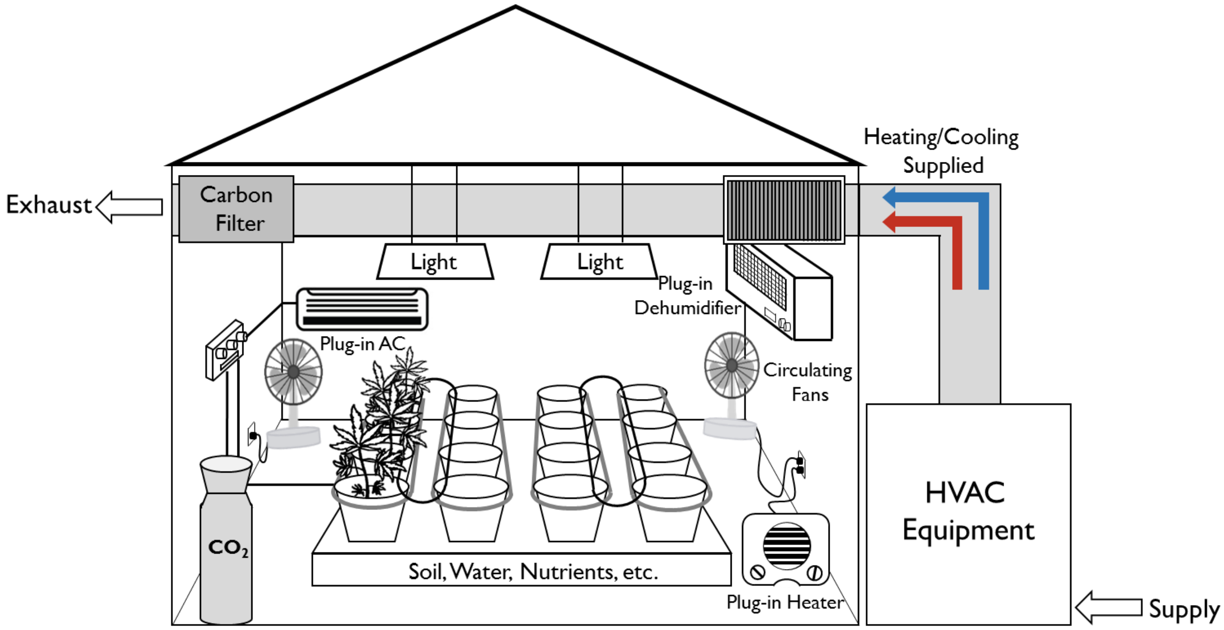

Figure B.8: *Overview of a modeled individual cannabis grow room highlighting the various systems necessary for maintaining the desired growth environment. This figure is representative of a general grow room and does represent the full facility model. The full facility model includes similar rooms, each individually outfitted to maintain climate requirements for various plant stages of growth further illustrated in Supplemental Figure 7. Individual room criteria are provided in Supplemental Table 3.*

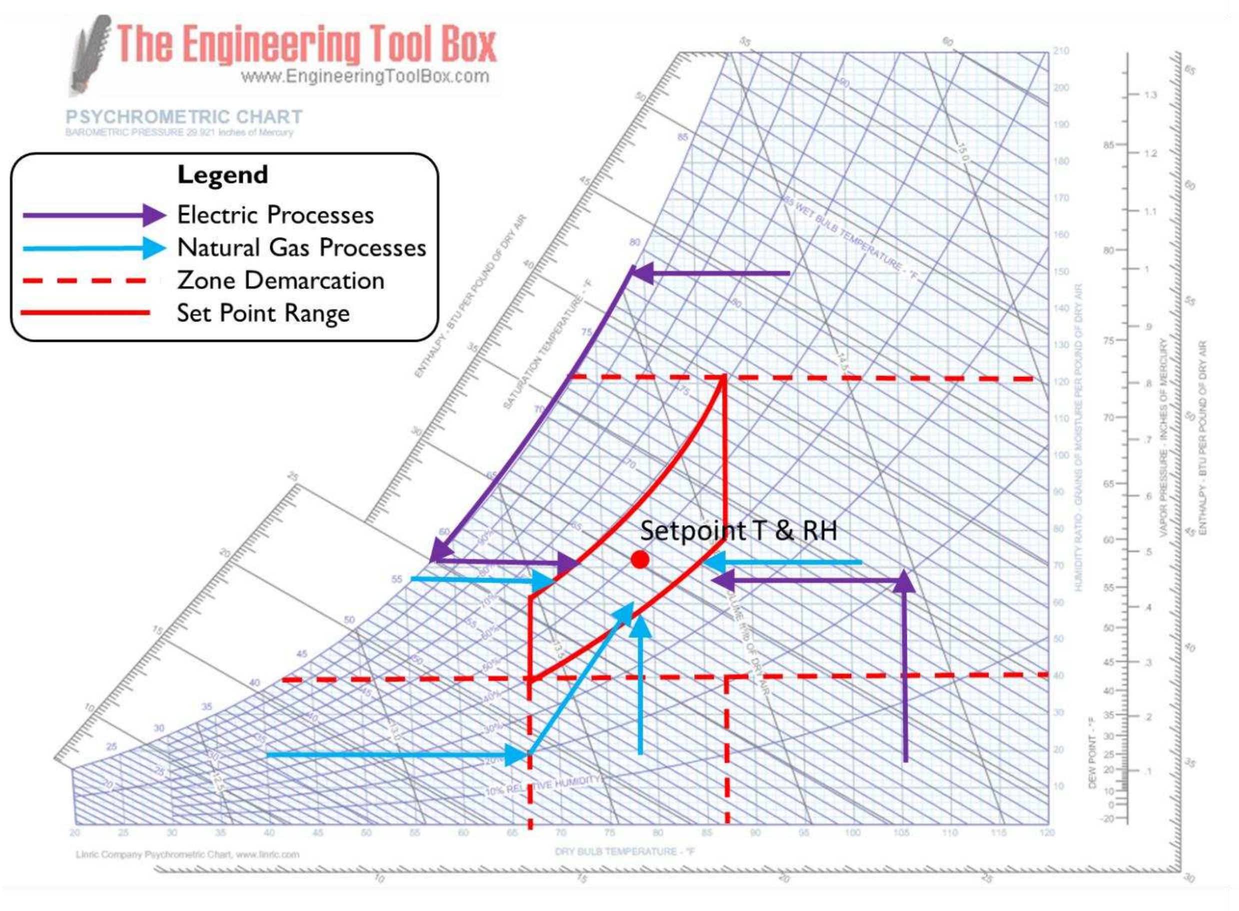

Figure B.9: *Energetic calculations were designed around principles of psychometrics and sub-divided into standard equipment handling zones. HVAC energy was calculated on an hourly basis depending on where the previous hour internal conditions mixed with outside conditions fell within the handling zones, see Appendix Method B.1 for more information* [92].

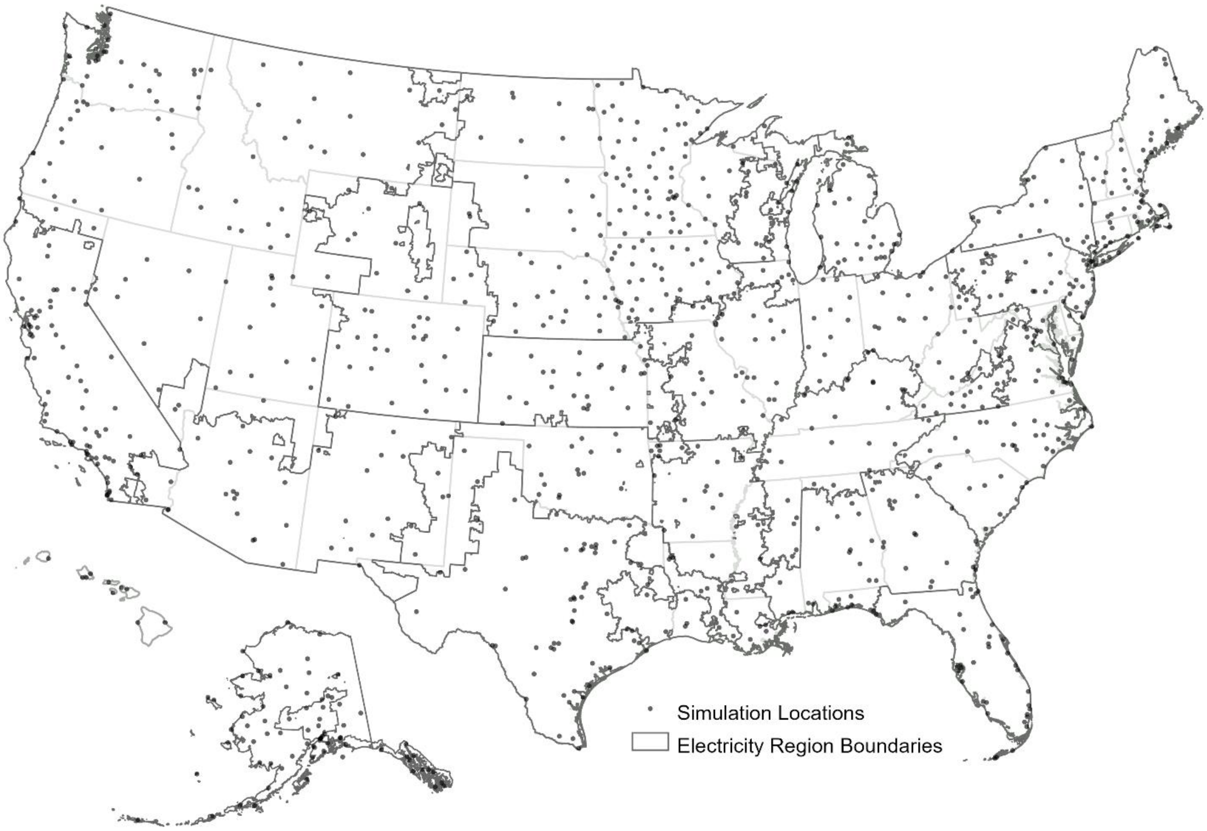

Figure B.10: *U.S. locations that were analyzed for GHG emissions from indoor cannabis production based on availability of Typical Meteorological Year (TMY) data*[54].

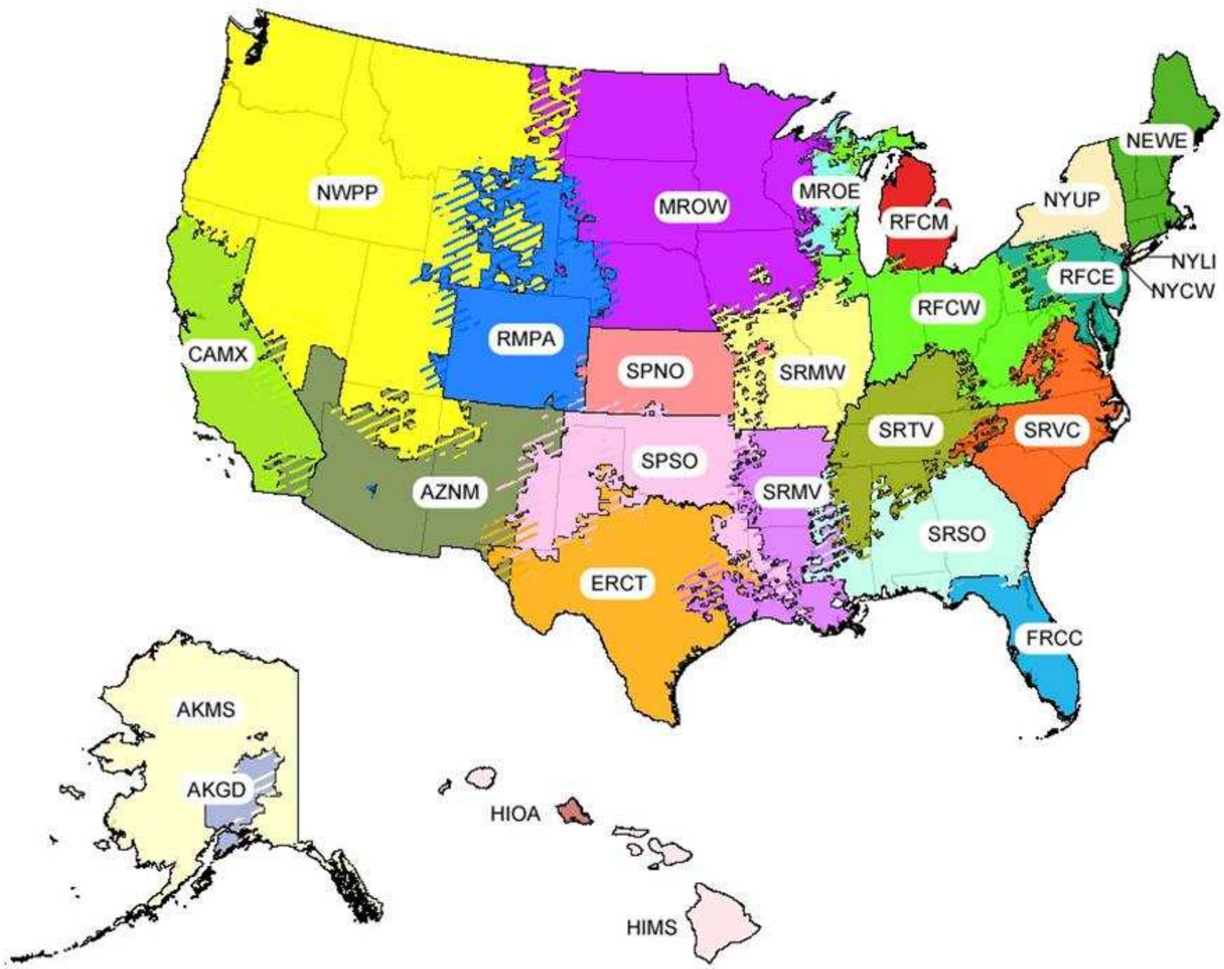

Figure B.11: *Map of eGRID Electricity Regions*[55]. *Quantitative GHG emissions for each region are provided in Appendix Table B.7.*

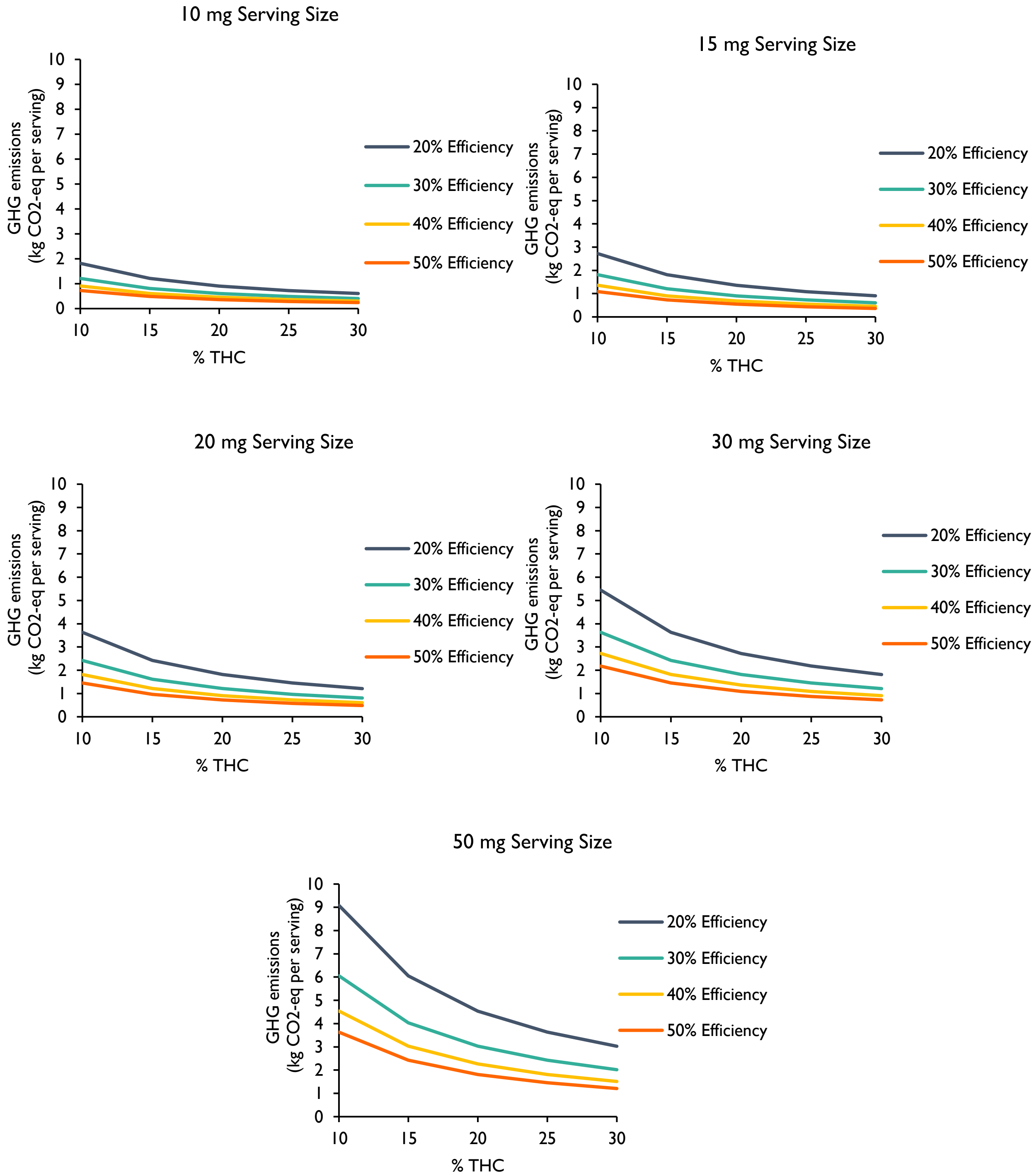

Figure B.12: *Impact on GHG emissions per serving size of THC when ranging values for THC serving size, delivery efficiency and THC content. Results are presented for five different serving sizes, 10 mg, 15 mg, 20 mg, 30 mg and 50 mg of THC.*

Method B.1: *Overview of the foundational calculations for indoor climate control performed within the cannabis cultivation model. Information can be cross-referenced with the open-source code provided on Github which provides a more complete outline of the HVAC modeling work: (https://github.com/haisummers/research).*

Definitions:

E_{supply}	*Energy from mass air flow supplied after HVAC modifications (Watt-hours)*
E_{stored}	*Energy from air in the room from previous hour of calculations (Watt-hours)*
E_{lights}	*Energy, in the form of heat, generated from high-intensity growth lights (Watt-hours)*
E_{lost}	*Energy, in the form of heat, lost through heat transfer through the walls*
$E_{exhaust}$	*Energy lost through mass air flow leaving facility (Watt-hours)*
E_{heat}	*Energy from mass air flow supplied from supplemental heater (Watt-hours)*
E_{cool}	*Energy from mass air flow supplied from supplemental air conditioner (Watt-hours)*
$E_{dehumid}$	*Energy from mass air flow supplied from supplemental dehumidifier (Watt-hours)*
$\dot{m}_{stored}$	*Mass flow rate of air stored in room, modeled to be one air exchange per hour (kg/s)*
$\dot{m}_{supply}$	*Mass flow rate of air from HVAC, modeled at a fixed 30 air exchanges per hour (kg/s)*
U	*Overall heat transfer coefficient for facility walls (W/m^2 K)*
SA	*Surface area of grow area walls (m^2)*
q	*Lighting intensity (W/m^2)*
h	*Enthalpy (J/kg dry air)*
h_{supply}	*Enthalpy supplied via HVAC, determined by set point temperature and relative humidity (J/kg dry air)*
h_{inside}	*Calculated end of hour enthalpy (J/kg dry air)*
$h_{inside,old}$	*Calculated end of hour enthalpy from previous hour (J/kg dry air)*
ω_{supply}	*Absolute humidity supplied via HVAC, determined by set point temperature and relative humidity (kg water/kg of dry)*
ω_{inside}	*Calculated end of hour absolute humidity (kg water/kg of dry air)*

$\omega_{inside,old}$ *Calculated end of hour absolute humidity from previous hour (kg water/kg of dry air)*

ET *Plant evapotranspiration, varies by plant growth stage (kg water/m^2 of cannabis canopy lighting)*

Energy calculations for HVAC and supplemental climate control systems were founded on mass and energy balances. Calculations were performed to represent a full-scale commercial cannabis operation with multiple grow rooms, each representing different stages of growth and thus a different set of climate requirements. Described here are the fundamental thermodynamic and heat transfer principles for one representative room. Individual grow room specifics can be cross referenced with growth stage set points from Appendix Table B.3.

Fundamentally, climate control energy calculations were determined on an hourly resolution. The energy requirements for each hour were determined from differences in the beginning and end of hour air humidity and enthalpy. Therefore, the first steps to understanding energy requirements was to solve for beginning and end of hour air humidity and enthalpy values through mass and energy balances. A water balance was determined for the grow room space as follows:

$$W_{gen} = W_{out} - W_{in} + W_{stored} \qquad \text{(Equation 1)}$$

$$ET = \dot{m}_{supply} \times \left(\omega_{inside} - \omega_{supplied}\right) + \dot{m}_{stored} \times \left(\omega_{inside} - \omega_{old}\right) \qquad \text{(Equation 2)}$$

The *supply* terms refer to values being supplied by the HVAC equipment, *stored* terms are values from the existing air conditions in the room and the *old* terms refer to final value at the end of the previous hour's calculations. The *old* absolute humidity value for the first hour of the year was assumed to be the value associated with temperature and humidity set points from daytime operations for each growth stage. Evapotranspiration, ET, rates vary when lights are on or off because plants release more water with increased photosynthetic activity and by plant growth stage due to vegetative surface area (see Appendix Table B.4). The mass flow of air from HVAC, *supply*, was modeled at a constant and fixed rate of 30 air changes per hour (ACH) due to cannabis plants needing access to fresh air and moisture from photosynthesis needing to be exhausted from the facility. The mass flow of *stored* air was modeled as the existing are in the room and therefore one ACH. The value for supplied absolute humidity is constant and determined through specific growth stage set points as it is assumed that the HVAC equipment can supply steady, set point conditions. Rearranging this water balance, the absolute humidity at the end of the hour can be determined from the following:

$$\omega_{inside} = \frac{\dot{m}_{supply} \times \omega_{supply} + \dot{m}_{stored} \times \omega_{old} + ET}{\dot{m}_{supply} + \dot{m}_{stored}} \qquad \text{(Equation 3)}$$

Similar to the water balance, a fundamental energy balance equation was set up for each grow room to determine the final enthalpy (using temperature and humidity) on an hourly basis. The foundational equation was as follows:

$$E_{stored} = E_{in} - E_{out} + E_{gen} \qquad \text{(Equation 4)}$$

$$E_{lights} = E_{stored} + E_{lost} + E_{exhaust} - E_{supply} - E_{cool} - E_{heat} - E_{dehumid} \qquad \text{(Equation 5)}$$

The first step in understanding the end of hour enthalpy was to determine if the constant supply of HVAC air at given set points (provided in Appendix Table B.3 for various stage of life) would be able to keep temperature and humidity within limits without needing supplemental climate control. Therefore, the first step in the energy balance was to set the energy associated with the supplemental controls (E_{heat}, E_{cool} and $E_{dehumid}$) equal to zero and solve the internal enthalpy at the end of the hour. If the end of hour enthalpy, function of temperature and humidity, is within the allowable range for that growth stage based on Appendix Table B.3, then E_{supply} is the only environmental control run for that hour. The end of hour temperature and humidity can be obtained from the final enthalpy as follows:

$$E_{lights} = E_{stored} + E_{lost} + E_{exhaust} - E_{supply} \qquad \text{(Equation 6)}$$

$$q \times A_{grow} = \dot{m}_{stored} \times \left(h_{inside} - h_{inside,old}\right) + U \times SA \times (T_{inside} - T_{\infty}) + \dot{m}_N \times \left(h_{inside} - h_{supply}\right) \qquad \text{(Equation 7)}$$

Rearranging to solve for h_{inside}:

$$h_{inside} = \frac{q \times A_{grow} + \dot{m}_{stored} \times h_{inside,old} - U \times SA \times (T_{inside} - T_{\infty}) + \dot{m}_{supply} \times h_{supply}}{\dot{m}_{stored} + \dot{m}_{supply}} \qquad \text{(Equation 8)}$$

The existing room enthalpy, $h_{inside,old}$, is carried over from the previous hour's energy balance calculations and h_{supply} is assumed to be delivered at the desired temperature and relative humidity from HVAC, q is the lighting intensity, and A_{grow} is the cannabis canopy grow area. The end of hour enthalpy,

h_{inside} is a function of the end of hour temperature, T_{inside} which is unknown at this stage and thus a guess is made. The end of hour temperature, T_{inside}, is determined from the same foundational energy balance, only now using temperatures and specific heats instead of enthalpies as follows:

$$T_{inside} = \frac{q \times A_{grow} + \dot{m}_{stored} \times c_{p_{air}} \times T_{inside,old} + U \times SA \times T_{\infty} + \dot{m}_{supply} \times c_{p_{air}} \times T_{set\ point}}{\dot{m}_{stored} \times c_{p_{air}} + U \times SA + \dot{m}_{supply} \times c_{p_{air}}} \quad \text{(Equation 9)}$$

The previous calculation for final temperature, $T_{inside,old}$, was determined by the previous hour's calculations and $T_{set\ point}$ was based on stage of life (Appendix Table B.3). This guess temperature allows for a guess enthalpy to be determined along with an absolute humidity from Equation 3. With the guess enthalpy and absolute humidity, a new temperature is determined through psychrometric principles. This new temperature is replaced for T_{inside} in Equation 8 to solve for a new h_{inside} and the process is iterated until the guess temperature and T_{inside} are within 0.01 tolerance of one another. Now an end of hour temperature and end of hour absolute humidity have been determined, allowing decision making for supplemental systems. If the end of hour temperature and end of hour absolute humidity are outside the allowable range, E_{heat}, E_{cool} *or* $E_{dehumid}$ are turned on and modeled as the remaining energy necessary to get the internal temperature and humidity within allowable limits.

Up to this point, the HVAC energy has not been discussed beyond being modeled as capable of delivering set point absolute humidity and enthalpy of air. The HVAC energy required to deliver constant set point air conditions was modeled at a fixed rate of 30 ACH and based upon psychrometric principles. The hourly weather data from NREL's TMY3 datasets determine what HVAC processes are necessary to deliver set points inside and are calculated using one of six psychrometric processes, as shown in Appendix Figure B.9. Cumulative environmental control energy for a given hour is determined by adding the fixed HVAC energy with supplemental equipment energy.

Table B.1: *Literature survey results to determine a representative, average, value for air exchanges per hour used in the indoor growth model.*

Source	Ventilation Rate (Air Exchanges per Hour)
Evan Mills [53]	30
Green CultureED [93]	12
Leafly [94]	60
Zamnesia [95]	20 - 30
Percy's Grow Room [96]	20 - 30
Royal Queen Seeds [97]	30 - 60
Big Buds Magazine [98]	12 - 20
Average	**30**

Table B.2: *Detailed greenhouse gas emissions contributions (kg CO_2-eq per kg-dried flower) for geographic locations of Figure 2 and Figure 3 of the manuscript.*

Parameter Name	Long Beach, CA	Seattle, WA	New York, NY	Phoenix, AZ	Jacksonville, FL	Chicago, IL	Denver, CO	Anchorage, AK	St. Louis, MO	Kaneohe Bay, HI
Simple Heating Load	231.06	250.71	164.17	45.79	118.89	186.59	151.15	217.93	155.76	30.73
Simple Cooling Load	3.57	2.22	3.49	85.41	4.48	6.18	12.81	0.04	16.29	23.02
Heating Associated w/ Heating & Humidification	219.17	707.95	716.62	279.98	170.26	910.89	970.59	1421.52	718.36	2.05
Humidification Associated w/ Heating & Humidification	81.35	233.86	307.36	236.36	67.08	361.08	606.12	545.09	297.84	0.70
Humidification	2.90	0.52	0.95	26.36	0.47	0.82	11.48	0.01	1.35	0.00
Humidification Associated w/ Humidification & Cooling	3.17	0.28	0.33	80.84	0.16	0.32	17.88	0.00	0.54	0.00
Cooling Associated w/ Humidification & Cooling	3.52	0.42	0.82	317.88	0.60	1.93	60.65	0.00	3.59	0.00
Dehumidification	123.96	26.41	197.36	162.52	910.58	299.53	31.09	9.25	603.28	1952.54
Dehumidification Reheat	240.69	48.10	231.18	91.49	576.10	186.75	24.44	11.56	241.37	759.63
Electricity from Lights	325.55	420.00	390.55	670.81	611.63	767.06	836.88	684.48	1095.53	1102.33
Water for Plants	1.87	1.87	1.87	1.87	1.87	1.87	1.87	1.87	1.87	1.87
Irrigation Pumping Load	0.59	0.76	0.71	1.22	1.11	1.39	1.52	1.24	1.99	2.00
Water Heating Load	0.78	1.01	0.94	1.62	1.47	1.85	2.02	1.65	2.64	2.66
CO2	573.98	573.98	573.98	573.98	573.98	573.98	573.98	573.98	573.98	573.98
Ammonium Nitrate (N)	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10
Triple Superphosphate (P)	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.03
Potassium Chloride (K)	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19
Soil	3.90	3.90	3.90	3.90	3.90	3.90	3.90	3.90	3.90	3.90
Soil Amendments	133.33	133.33	133.33	133.33	133.33	133.33	133.33	133.33	133.33	133.33
Neem Oil	7.51	7.51	7.51	7.51	7.51	7.51	7.51	7.51	7.51	7.51
Neem Oil (water)	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Neem Oil (Soap)	1.21	1.21	1.21	1.21	1.21	1.21	1.21	1.21	1.21	1.21
Fungicides	7.39	7.39	7.39	7.39	7.39	7.39	7.39	7.39	7.39	7.39
Extractor Fan Electricity	26.68	34.43	32.01	54.98	50.13	62.87	68.60	56.10	89.80	90.35
Intake Fan Electricity	26.68	34.43	32.01	54.98	50.13	62.87	68.60	56.10	89.80	90.35
Circulation Fan Electricity	33.25	42.90	39.89	68.51	62.47	78.34	85.47	69.91	111.89	112.58
Landfill Operations	1.30	1.30	1.30	1.30	1.30	1.30	1.30	1.30	1.30	1.30

Landfill Emissions	12.24	12.24	12.24	12.24	12.24	12.24	12.24	12.24	12.24	12.24
Transportation to Landfill	18.18	18.18	18.18	18.18	18.18	18.18	18.18	18.18	18.18	18.18
Secondary Air Conditioning	20.95	25.08	23.59	46.05	40.90	43.81	48.36	34.17	66.32	76.65
Secondary Dehumidification	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Secondary Heating	0.18	1.72	1.63	0.49	0.38	5.79	6.94	8.59	6.85	0.00
Transportation, Lorry, to facility	111.11	111.11	111.11	111.11	111.11	111.11	111.11	111.11	111.11	111.11
Transportation, Truck, to facility	127.51	127.51	127.51	127.51	127.51	127.51	127.51	127.51	127.51	127.51
Transportation, passenger vehicle, to facility	7.38	7.38	7.38	7.38	7.38	7.38	7.38	7.38	7.38	7.38
Carbon stored in product	-1.76	-1.76	-1.76	-1.76	-1.76	-1.76	-1.76	-1.76	-1.76	-1.76
Carbon stored in landfill	-69.76	-69.76	-69.76	-69.76	-69.76	-69.76	-69.76	-69.76	-69.76	-69.76
Totals	2282.84	2769.57	3082.39	3164.06	3605.63	3916.85	3943.36	4056.43	4441.97	5184.37

Table B.3: *Fundamental inputs for cannabis cultivation tolerances for each grow room and stage of growth* [99].

Parameter Name	Clone	Vegetative	Flower	Cure
Temperature High (°C)	26.7	23.9	29.4	23.9
Temperature Low (°C)	21.1	15.6	21.1	15.6
Relative Humidity High	70%	50%	50%	50%
Relative Humidity Low	40%	40%	40%	30%
Lighting Intensity (W/m^2)	404	404	673	30
Lighting Duration (hours/day)	24	18	12	18
CO_2 (ppm)	400*	700	1400	400*

**400 ppm was assumed for atmospheric CO_2, therefore no additional CO_2 was supplied during this stage of growth*

Table B.4: *Evapotranspiration equations as a function of lighting intensity (LI, W/m^2) for each plant stage of life*[68].

Evapotranspiration Equations for Stage of Life	Equation	Units
Clone	0	kg H_2O/m^2-hour
Vegetative	$0.00024 * LI + 0.0016$	kg H_2O/m^2-hour
Flower	$0.0012 * LI + 0.0084$	kg H_2O/m^2-hour
Cure	$0.0012 * LI + 0.0084$	kg H_2O/m^2-hour
Night (when lights are off)	30	% of daytime amounts

Table B.5: *Equipment parameters and material inputs for indoor cannabis cultivation.*

Parameter Name	Value	Units
Facility Size	1393.55	m^2
Useable Grow Area	938.18	m^2
Facility Height	4.57	meters
Exterior Wall Thickness	0.30	meters
Thermal Conductivity	0.06	W/m*K
Convective Heat Transfer Coefficient Inside	30	W/m^2-K
Convective Heat Transfer Coefficient Outside	30	W/m^2-K
Harvest Quantity	6.19	harvest/year
COP Chiller	3.25	
Heating Efficiency	80	% of energy delivered
Clone Room Duration	3.14	weeks/harvest
Vegetative Growth Duration	7.14	weeks/harvest
Flowering Duration	8.14	weeks/harvest
Curing Duration	2	weeks/harvest
Days Between Plant Stages	2	days/stage
Number of Circulating Fans Needed	0.12	fans/m^2 of facility
Cumulative Circulating Fan Power	36.08	HP/hr
Extractor Fan Power	28.96	HP/hr
Intake Fan Power	28.96	HP/hr
Water Pump Power	0.00	kWh/gallon
Well Water Temp	16.30	deg C
Delivered Water Temp	19.72	deg C
Clone Grow Area Fraction	3.5	% of Usable Grow Area
Vegetative Grow Area Fraction	22.5	% of Usable Grow Area
Flower Grow Area Fraction	66.2	% of Usable Grow Area
Cure Grow Area Fraction	7.8	% of Usable Grow Area
Plant Density	2.69	plants/m^2
Number of Plants	1669	plants/harvest-flower
Plant Yield	0.44	kg/m^2-harvest
Water Amount	1.00	gal/plant/day
Coco Coir as Soil	0.03	m^3/plant
Soil Amendments (Perlite)	0.01	m^3/plant
Biofungicide (Folpet)	0.29	kg/plant
Neem oil for insecticide	0.28	liters/plant-cycle
water mixed with neem oil application	11.00	liters/plant-cycle
Surfactant mixed with neem oil application	0.05	liters/plant-cycle
Waste from Plants	7.73	lb. waste /lb. product
Clone Soil Waste	0.38	kg/plant
Vegetative Soil Waste	0.02	m^3/plant
Flower Soil Waste	0.03	m^3/plant

Table B.6: *Detailed nutrient feeding schedule for soil based cannabis plants obtained from Fox Farm Soil & Nutrient Company* [71].

Fox Farm Soil & Fertilizer Company Product Names		**Vegetative Amounts (teaspoons per gallon of water, two feedings per week)**						
Week #	**Seedlings and Cuttings**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Big Bloom (NPK: 0-0.5-0.7)	6	6	6	6	3	3	3	3
Grow Big (NPK: 6-4-4)			2	3	3	3	3	2
Tiger Bloom (NPK: 2-8-4)								2
Flowers Kiss (NPK: 1-0.3-0.1)			2	2	2	2	2	2
Boomerang (NPK: 2-0.2-0.3)	1	1	1	1	1	1	1	1
Kangaroots (NPK: 0.8-0.1-0)			0.5		0.5	0.5	0.5	
Microbe Brew (NPK: 1-0.3-0.2)			0.5	0.5				0.5
Wholly Mackerel (NPK: 3-1-0)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	
Kelp Me Kelp You (NPK: 0.5-0-0.5)				0.25	0.25	0.25	0.25	0.5
Bembe (NPK: 0-1-3)								
Open Sesame (NPK: 5-45-19)						0.25	0.25	0.25
Beasite Bloomz (NPK: 0-50-30)								
Cha Ching (NPK: 9-50-10)								

	Flower Amounts (teaspoons per gallon of water, two feedings per week)							
Week #	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Big Bloom (NPK: 0-0.5-0.7)	3	3	3	3	3	3	3	
Grow Big (NPK: 6-4-4)	2	2	2	1				
Tiger Bloom (NPK: 2-8-4)	2	2	2	2	2	1	1	
Flowers Kiss (NPK: 1-0.3-0.1)	2	2	2	2	2	2	2	
Boomerang (NPK: 2-0.2-0.3)	1	1						
Kangaroots (NPK: 0.8-0.1-0)	1							
Microbe Brew (NPK: 1-0.3-0.2)		0.5		0.5				
Wholly Mackerel (NPK: 3-1-0)								
Kelp Me Kelp You (NPK: 0.5-0-0.5)	0.5	0.5	0.5	0.25				
Bembe (NPK: 0-1-3)			3	3	3	3	3	
Open Sesame (NPK: 5-45-19)	0.25	0.25						
Beasite Bloomz (NPK: 0-50-30)			0.25	0.25				
Cha Ching (NPK: 9-50-10)					0.25	0.25	0.25	0.25

Table B.7: *Electricity GHG emissions by eGRID U.S. subregion* [55]*. Visual representation of each region can be found in Appendix Figure B.11.*

eGRID subregion acronym	eGRID subregion name	Total output emission rates (lb CO_2-eq/MWh)	Grid Gross Loss (%)	Total GHGs (grams CO_2-eq/kWh)
AKGD	ASCC Alaska Grid	1,045.0	5.12%	499.60
AKMS	ASCC Miscellaneous	527.0	5.12%	251.93
AZNM	WECC Southwest	1,027.5	4.80%	489.61
CAMX	WECC California	498.7	4.80%	237.62
ERCT	ERCOT All	936.1	4.87%	446.34
FRCC	FRCC All	936.1	4.88%	446.42
HIMS	HICC Miscellaneous	1,119.1	5.14%	535.12
HIOA	HICC Oahu	1,682.6	5.14%	804.58
MROE	MRO East	1,689.7	4.88%	805.75
MROW	MRO West	1,249.2	4.88%	595.71
NEWE	NPCC New England	527.6	4.88%	251.58
NWPP	WECC Northwest	643.4	4.80%	306.55
NYCW	NPCC NYC/Westchester	597.8	4.88%	285.06
NYLI	NPCC Long Island	1,193.1	4.88%	568.95
NYUP	NPCC Upstate NY	253.9	4.88%	121.07
RFCE	RFC East	720.0	4.88%	343.34
RFCM	RFC Michigan	1,321.2	4.88%	630.04
RFCW	RFC West	1,174.0	4.88%	559.86
RMPA	WECC Rockies	1,281.9	4.80%	610.83
SPNO	SPP North	1,171.6	4.88%	558.71
SPSO	SPP South	1,172.8	4.88%	559.25
SRMV	SERC Mississippi Valley	858.4	4.88%	409.33
SRMW	SERC Midwest	1,676.8	4.88%	799.61
SRSO	SERC South	1,033.5	4.88%	492.83
SRTV	SERC Tennessee Valley	1,038.1	4.88%	495.05
SRVC	SERC Virginia/Carolina	747.5	4.88%	356.47

Table B.8: *Emissions data for cradle-to-gate production, transportation and waste for all non-electric based energy and material inputs* [38]*. Ecoinvent v3.4 (cutoff datasets) and the National Renewable Energy Laboratory's U.S. LCI were used for data collection* [37]*. Exact process names and methods are provided in Supplemental Table 9.*

Parameter Name	**Units**	**Greenhouse Gas Emissions (kg CO_2-eq)**
Natural Gas	per kg	3.06E+00
Tap Water	per kg	7.45E-04
Carbon Dioxide	per kg	8.79E-01
Peat Moss	per m^3	1.32E+02
Biofungicide (Folpet)	per kg	4.12E+00
Soil Amendments (Perlite)	per kg	1.44E+00
Pesticides (Pyrethroid-compound)	per kg	1.78E+01
Landfill Operations	per kg	5.60E-03
Ammonium Nitrate	per kg	8.80E+00
Triple Superphosphate	per kg	1.94E+00
Potassium Chloride	per kg	5.22E-01
Nutrient Supply from Coconut Husk, as N	per kg	5.93E-02
Palm Oil, Refined, to Generic Market for Vegetable Oil	per kg	4.90E+00
Surfactant Production	per kg	3.92E+00
Transportation, lorry	per ton-km	1.69E-01
Transportation, light commercial vehicle	per ton-km	1.94E+00
Transportation, medium-sized passenger car	per ton-km	5.62E-01

Table B.9: *Life cycle inventory data descriptions for emissions obtained from ecoinvent v3.4 and U.S. LCI processes*[37,38]. *GHG emissions values from these processes are provided in Appendix Table B.8.*

Variable Name	**Process Details in Ecoinvent v3.4 or U.S. LCI**
Natural Gas	Ecoinvent - market for natural gas, from high pressure network (1-5 bar), at service station | natural gas, from high pressure network (1-5 bar), at service station | Cutoff, S - GLO USLCI - Natural gas, combusted in industrial equipment
Tap Water	EcoInvent - tap water production, underground water with chemical treatment | tap water | Cutoff, S - RoW
Carbon Dioxide	Ecoinvent - Carbon dioxide production, liquid | carbon dioxide, liquid | Cutoff, S – RoW
Peat Moss	Ecoinvent - Peat moss production, horticultural use | peat moss | Cutoff, S – RoW
Biofungicide (Folpet)	Ecoinvent - Folpet production | folpet | Cutoff, S - RoW
Soil Amendments (Perlite)	Ecoinvent - Expanded perlite production | expanded perlite | Cutoff, S – RoW
Pesticides (Pyrethroid-compound)	Ecoinvent - Pyrethroid-compound production | pyrethroid-compound | Cutoff, S - RoW
Landfill Operations	Ecoinvent - Process-specific burden, sanitary landfill | process-specific burden, sanitary landfill | Cutoff, S - RoW
Ammonium Nitrate	Ecoinvent - Ammonium Nitrate Production, as N | Cutoff, RoW
Triple Superphosphate	Ecoinvent - Triple Superphosphate Production, as P | Cutoff, RoW
Potassium Chloride	Ecoinvent - Potassium Chloride Production, as K | Cutoff, RoW
Nutrient Supply from Coconut Husk, as N	Ecoinvent - Nutrient Supply from Coconut Husk, as N | Cutoff, RoW
Palm Oil, Refined, to Generic Market for Vegetable Oil	Ecoinvent - Palm oil, refined, to generic market for vegetable oil | vegetable oil, refined | Cutoff, S - RoW
Surfactant Production	Ecoinvent - Soap production | soap | Cutoff, S - RoW
Transportation, lorry	Ecoinvent - Transport, freight, lorry 16-32 metric ton, EURO5 | transport, freight, lorry 16-32 metric ton, EURO5 | Cutoff, S - RoW
Transportation, light commercial vehicle	Ecoinvent - Transport, freight, light commercial vehicle | transport, freight, light commercial vehicle | Cutoff, S - RoW
Transportation, medium-sized passenger car	Ecoinvent - Market for transport, passenger car, medium size, petrol, EURO 5 | transport, passenger car, medium size, petrol, EURO 5 | Cutoff, S - RoW

Table B.10: *Detailed carbon accounting of waste streams modeled within the system boundary, based on Lee et al.* [74].

Variable Description	Value	Units
Total Mass Landfilled	392.17	tonnes/yr
Carbon Accounting		
Landfilled C	43.94	tonnes C/yr
Collected and Combusted CH4 (CO_2 emissions, biogenic)	5.92	tonnes C/yr
Oxidized CH4 (CO_2 emission, biogenic)	3.87	tonnes C/yr
Non-collected CH_4 emissions	0.64	tonnes C/yr
CO2 from waste decomposition (biogenic)	1.46	tonnes C/yr
Stored Carbon in Landfill	32.05	tonnes C/yr
Gas Accounting		
Total Released CH_4	0.86	tonnes CH4/yr
Total Released CO_2 (no burden applied)	35.88	tonnes CO_2/yr
Total Biogenic CO_2 (no burden applied)	5.37	tonnes CO_2/yr
Stored	117.51	tonnes CO_2/yr
GHG Emissions Accounting		
Total Released CH_4	20.62	tonnes CO_2-eq/yr
Total Degraded CO_2 (no burden applied)	35.88	tonnes CO_2-eq/yr
Total Biogenic CO_2 (no burden applied)	5.37	tonnes CO_2-eq/yr
Stored	117.51	tonnes CO_2-eq/yr
System Boundary Accounting		
Total GHG Emissions	20.62	tonnes CO_2-eq/yr
Total Stored Landfill	117.51	tonnes CO_2-eq/yr

Table B.11: *Sensitivity results from air changes per hour (ACH) on GHG emissions (kg CO_2-eq per kg-dried flower) from indoor cannabis production at ten locations in the U.S. These results are the raw values of Figure 3in the manuscript.*

	GHG Emissions (kg CO_2-eq per kg-dried flower)					
	10 ACH	20 ACH	30 ACH (Baseline)	40 ACH	50 ACH	60 ACH
Long Beach, CA	1291.00	1892.05	2282.84	2842.30	3387.62	3941.95
Seattle, WA	1568.89	2304.13	2769.57	3445.61	4107.25	4785.67
New York, NY	1643.25	2485.96	3082.39	3874.41	4660.98	5451.83
Phoenix, AZ	2027.52	2815.28	3164.06	3861.86	4545.11	5220.41
Jacksonville, FL	2107.07	3053.02	3605.63	4477.68	5335.19	6184.09
Chicago, IL	2389.41	3401.39	3916.85	4812.45	5700.91	6597.84
Denver, CO	2479.09	3059.39	3943.36	4814.95	5675.22	6551.74
Anchorage, AK	2332.96	3411.15	4056.43	5032.36	6006.40	6998.35
St. Louis, MO	2987.25	4069.45	4441.97	5364.27	6271.65	7184.72
Kaneohe Bay, HI	3274.71	4588.58	5184.37	6363.61	7536.29	8647.05

Table B.12: *Results for indoor cannabis cultivation GHGs, electricity consumption, natural gas consumption, and electricity emissions for each location analyzed.*

TMY3 Filename	Site	GHG Emissions (kg CO_2-eq/kg-dried flower)	Electricity (kWh/kg-dried flower)	NG (MJ/kg-dried flower)	GHG electricity (grams CO_2-eq/kWh)
690150TYA.CSV	TWENTYNINE PALMS	2513.44	2473.67	17554.93	237.62
690190TYA.CSV	ABILENE DYESS AFB	3351.40	2841.16	20177.15	446.34
690230TYA.CSV	WHIDBEY ISLAND NAS	2815.03	1835.65	23411.70	306.55
699604TYA.CSV	YUMA MCAS	3167.38	2978.42	13367.15	489.61
700197TYA.CSV	SELAWIK	4306.06	1784.33	52341.84	251.93
700260TYA.CSV	BARROW W POST-W ROGERS ARPT [NSA - ARM]	5099.77	1775.20	66840.70	251.93
700637TYA.CSV	DEADHORSE	4855.05	1777.09	62344.07	251.93
701043TYA.CSV	POINT HOPE (AWOS)	4385.20	1775.76	53811.34	251.93
701195TYA.CSV	SHISHMAREF (AWOS)	4289.29	1777.83	52066.03	251.93
701330TYA.CSV	KOTZEBUE RALPH WEIN MEMORIAL	4370.31	1790.45	53601.25	251.93
701625TYA.CSV	ANAKTUVUK PASS	4671.87	1775.25	59001.42	251.93
701718TYA.CSV	AMBLER	4266.19	1783.57	51629.20	251.93
701740TYA.CSV	BETTLES FIELD	4380.14	1806.22	53714.36	251.93
701780TYA.CSV	TANANA RALPH M CALHOUN MEM AP	4162.15	1801.57	49767.71	251.93
701940TYA.CSV	FORT YUKON	4419.96	1782.85	54461.03	499.60
702000TYA.CSV	NOME MUNICIPAL ARPT	4095.95	1786.09	48664.68	251.93
702005TYA.CSV	SAINT MARY`S (AWOS)	3844.56	1782.49	44072.66	251.93
702035TYA.CSV	SAVOONGA	4124.08	1774.74	49099.24	251.93
702040TYA.CSV	GAMBELL	4134.10	1775.63	49280.57	251.93
702070TYA.CSV	UNALAKLEET FIELD	3972.07	1779.49	46400.34	251.93
702075TYA.CSV	ANVIK	3934.15	1780.31	45666.77	251.93
702084TYA.CSV	EMMONAK	3852.81	1798.84	44098.09	251.93
702185TYA.CSV	MEKORYUK	3790.13	1777.27	43071.71	251.93
702186TYA.CSV	HOOPER BAY	3869.55	1778.98	44485.10	251.93
702190TYA.CSV	BETHEL AIRPORT	3865.05	1792.77	44448.32	251.93
702225TYA.CSV	HUSLIA	4177.58	1783.12	50027.92	251.93
702310TYA.CSV	MCGRATH ARPT	4651.71	1796.71	50419.92	251.93
702320TYA.CSV	ANIAK AIRPORT	3863.05	1782.36	44407.28	251.93
702460TYA.CSV	MINCHUMINA	4532.55	1796.92	48058.06	499.60
702495TYA.CSV	HAYES RIVER	4157.59	1820.85	41048.12	499.60
702510TYA.CSV	TALKEETNA STATE ARPT	4183.05	1796.31	41889.89	499.60
702590TYA.CSV	KENAI MUNICIPAL AP	3996.91	1789.99	38579.91	499.60
702595TYA.CSV	SOLDOTNA	4048.73	1780.20	39465.90	499.60
702600TYA.CSV	NENANA MUNICIPAL AP	4592.45	1793.73	49261.78	499.60
702606TYA.CSV	CHULITNA	4197.33	1793.77	41999.45	499.60
702607TYA.CSV	HOONAH	3316.42	1810.59	34387.33	251.93
702610TYA.CSV	FAIRBANKS INTL ARPT	4569.33	1810.82	48806.73	499.60
702647TYA.CSV	HEALY RIVER AIRPORT	4259.59	1787.96	43184.88	499.60

702650TYA.CSV	FAIRBANKS/EIELSON A	4425.87	1804.60	46215.72	499.60
702670TYA.CSV	BIG DELTA ALLEN AAF	4071.78	1806.39	48127.26	499.60
702710TYA.CSV	GULKANA INTERMEDIATE FIELD	4177.47	1780.38	50142.50	251.93
702720TYA.CSV	ANCHORAGE/ELMENDORF	3893.51	1813.83	36481.82	499.60
702725TYA.CSV	LAKE HOOD SEAPLANE	3889.38	1785.51	36649.12	499.60
702730TYA.CSV	ANCHORAGE INTL AP	4056.43	1792.92	39638.99	499.60
702735TYA.CSV	ANCHORAGE MERRILL FIELD	3917.86	1810.74	36929.85	499.60
702740TYA.CSV	PALMER MUNICIPAL	3398.48	1799.23	35965.82	499.60
702746TYA.CSV	BIRCHWOOD	3985.05	1785.97	38274.18	499.60
702750TYA.CSV	VALDEZ WSO	3442.91	1790.39	36813.73	251.93
702756TYA.CSV	VALDEZ PIONEER FIEL	3433.56	1781.55	36617.67	251.93
702757TYA.CSV	WHITTIER	3425.96	1788.90	36516.15	499.60
702770TYA.CSV	SEWARD	3856.35	1789.08	36003.42	499.60
702910TYA.CSV	NORTHWAY AIRPORT	4447.64	1795.00	54967.58	251.93
702960TYA.CSV	CORDOVA	3404.72	1789.99	36133.97	499.60
702986TYA.CSV	BIG RIVER LAKE	3584.17	1830.71	39126.57	499.60
703080TYA.CSV	ST PAUL ISLAND ARPT	3591.38	1778.35	39544.47	251.93
703160TYA.CSV	COLD BAY ARPT	3420.77	1781.87	36455.20	251.93
703165TYA.CSV	SAND POINT	3426.20	1780.05	36495.90	251.93
703210TYA.CSV	DILLINGHAM (AMOS)	3656.91	1788.50	40667.68	251.93
703260TYA.CSV	KING SALMON ARPT	3660.96	1797.53	40748.87	251.93
703330TYA.CSV	PORT HEIDEN	3613.72	1777.04	39954.57	251.93
703400TYA.CSV	ILIAMNA ARPT	3535.48	1797.96	38444.22	251.93
703407TYA.CSV	SLEETMUTE	3874.89	1860.44	44217.53	251.93
703410TYA.CSV	HOMER ARPT	3931.92	1794.82	37370.02	499.60
703430TYA.CSV	MIDDLETON ISLAND AUT	3330.77	1778.86	34824.28	251.93
703500TYA.CSV	KODIAK AIRPORT	3283.08	1797.53	33896.94	251.93
703606TYA.CSV	TOGIAC VILLAGE AWOS	3602.09	1784.92	39640.09	251.93
703610TYA.CSV	YAKUTAT STATE ARPT	3322.59	1796.11	34621.32	251.93
703620TYA.CSV	SKAGWAY AIRPORT	3299.95	1797.32	34211.89	251.93
703670TYA.CSV	GUSTAVUS	3368.28	1785.42	35435.11	251.93
703710TYA.CSV	SITKA JAPONSKI AP	3212.56	1805.06	32589.90	251.93
703810TYA.CSV	JUNEAU INT'L ARPT	3243.89	1809.40	33123.27	251.93
703855TYA.CSV	KAKE SEAPLANE BASE	3246.42	1790.21	33209.63	251.93
703860TYA.CSV	PETERSBURG	3259.93	1800.22	33411.13	251.93
703870TYA.CSV	WRANGELL	3200.90	1804.36	32328.89	251.93
703884TYA.CSV	HYDABURG SEAPLANE	3198.41	2118.69	30852.71	251.93
703950TYA.CSV	KETCHIKAN INTL AP	3204.68	1857.66	32206.01	251.93
703980TYA.CSV	ANNETTE ISLAND AP	2963.74	1814.40	28054.66	251.93
704140TYA.CSV	SHEMYA AFB	3503.20	1777.87	37952.44	251.93
704540TYA.CSV	ADAK NAS	3426.11	1776.83	36563.09	251.93
704890TYA.CSV	DUTCH HARBOR	3390.05	1779.48	35849.84	251.93
722010TYA.CSV	KEY WEST INTL ARPT	4007.52	4902.86	15385.13	446.42

722015TYA.CSV	KEY WEST NAS	4023.72	4937.86	15395.48	446.42
722016TYA.CSV	MARATHON AIRPORT	4198.01	5254.98	15981.89	446.42
722020TYA.CSV	MIAMI INTL AP	3828.22	4515.25	15279.22	446.42
722024TYA.CSV	MIAMI/OPA LOCKA	3832.77	4518.49	15339.31	446.42
722025TYA.CSV	FORT LAUDERDALE HOLLYWOOD INT	3910.62	4693.45	15327.86	446.42
722026TYA.CSV	HOMESTEAD AFB	3878.45	4559.17	15834.42	446.42
722029TYA.CSV	MIAMI/KENDALL-TAMIA	3715.36	4275.20	15184.32	446.42
722030TYA.CSV	WEST PALM BEACH INTL ARPT	3785.96	4389.06	15537.21	446.42
722038TYA.CSV	NAPLES MUNICIPAL	3605.94	4052.47	15004.34	446.42
722039TYA.CSV	FORT LAUDERDALE	3784.36	4406.62	15364.22	446.42
722040TYA.CSV	MELBOURNE REGIONAL AP	3679.44	4157.94	15483.43	446.42
722045TYA.CSV	VERO BEACH MUNICIPAL ARPT	3759.81	4323.22	15601.21	446.42
722050TYA.CSV	ORLANDO INTL ARPT	3619.44	3996.21	15708.99	446.42
722053TYA.CSV	ORLANDO EXECUTIVE AP	3642.99	3992.67	16158.79	446.42
722055TYA.CSV	OCALA MUNI (AWOS)	3486.85	3535.69	17008.60	446.42
722056TYA.CSV	DAYTONA BEACH INTL AP	3557.42	3816.27	16043.73	446.42
722057TYA.CSV	ORLANDO SANFORD AIRPORT	3492.10	3720.53	15618.81	446.42
722060TYA.CSV	JACKSONVILLE INTL ARPT	3519.58	3599.78	17112.26	446.42
722065TYA.CSV	JACKSONVILLE NAS	3605.63	3825.42	16839.63	446.42
722066TYA.CSV	MAYPORT NS	3543.72	3720.15	16574.84	446.42
722068TYA.CSV	JACKSONVILLE/CRAIG	3566.65	3764.78	16627.78	446.42
722070TYA.CSV	SAVANNAH INTL AP	3650.22	3389.34	18281.42	492.83
722080TYA.CSV	CHARLESTON INTL ARPT	3233.42	3394.05	19213.74	356.47
722085TYA.CSV	BEAUFORT MCAS	3183.13	3275.91	19066.37	356.47
722103TYA.CSV	ST LUCIE CO INTL	3635.82	3983.70	16098.20	446.42
722104TYA.CSV	ST PETERSBURG ALBERT WHITTED	3760.51	4327.95	15574.07	446.42
722106TYA.CSV	FORT MYERS PAGE FIELD	3835.06	4493.94	15577.58	446.42
722108TYA.CSV	SOUTHWEST FLORIDA I	3731.31	4254.40	15641.90	446.42
722110TYA.CSV	TAMPA INTERNATIONAL AP	3673.55	4077.61	16027.57	446.42
722115TYA.CSV	SARASOTA BRADENTON	3744.65	4230.04	16082.22	446.42
722116TYA.CSV	ST PETERSBURG CLEAR	3732.05	4163.67	16387.70	446.42
722119TYA.CSV	LAKELAND LINDER RGN	3693.27	3999.11	17002.12	446.42
722135TYA.CSV	ALMA BACON COUNTY AP	3704.06	3364.32	19476.14	492.83
722136TYA.CSV	BRUNSWICK GOLDEN IS	3856.32	3667.69	19485.57	492.83
722137TYA.CSV	BRUNSWICK MALCOLM MCKINNON AP	3753.58	3768.73	16768.43	492.83
722140TYA.CSV	TALLAHASSEE REGIONAL AP [ISIS]	3504.39	3481.50	17791.48	446.42
722146TYA.CSV	GAINESVILLE REGIONAL AP	3568.38	3689.02	17271.24	446.42
722160TYA.CSV	ALBANY DOUGHERTY COUNTY AP	3641.49	3382.20	18187.95	492.83
722166TYA.CSV	VALDOSTA WB AIRPORT	3793.27	3715.77	17955.88	492.83
722170TYA.CSV	MACON MIDDLE GA REGIONAL AP	3651.34	3201.03	19981.16	492.83
722175TYA.CSV	WARNER ROBINS AFB	3759.23	3179.70	22121.66	492.83
722180TYA.CSV	AUGUSTA BUSH FIELD	3581.35	3045.72	20104.06	492.83
722190TYA.CSV	ATLANTA HARTSFIELD INTL AP	3543.79	2867.96	21008.57	492.83

722195TYA.CSV	FULTON CO ARPT BROW	3613.24	2965.62	21388.27	492.83
722196TYA.CSV	DEKALB PEACHTREE	3676.65	2925.69	22888.00	492.83
722210TYA.CSV	VALPARAISO ELGIN AFB	3778.38	3501.03	19599.16	492.83
722215TYA.CSV	CRESTVIEW BOB SIKES AP	3759.03	3600.35	18362.93	492.83
722223TYA.CSV	PENSACOLA REGIONAL AP	3830.84	3861.85	17330.14	492.83
722225TYA.CSV	PENSACOLA FOREST SHERMAN NAS	3833.94	3761.78	18279.34	492.83
722226TYA.CSV	WHITING FIELD NAAS	3715.36	3515.72	18325.91	492.83
722230TYA.CSV	MOBILE REGIONAL AP	3738.63	3528.86	18633.72	492.83
722235TYA.CSV	MOBILE DOWNTOWN AP	3705.27	3528.13	18037.06	492.83
722245TYA.CSV	PANAMA CITY BAY CO	3876.96	3910.71	17725.23	492.83
722250TYA.CSV	FORT BENNING LAWSON	3676.72	3010.74	22135.83	492.83
722255TYA.CSV	COLUMBUS METROPOLITAN ARPT	3657.98	3287.18	19335.48	492.83
722260TYA.CSV	MONTGOMERY DANNELLY FIELD	3621.97	3201.89	19445.56	492.83
722265TYA.CSV	MAXWELL AFB	3736.54	3270.20	20901.87	492.83
722267TYA.CSV	TROY AF	3698.86	3336.61	19634.34	492.83
722268TYA.CSV	DOTHAN MUNICIPAL AP	3668.12	3332.62	19106.17	495.05
722269TYA.CSV	CAIRNS FIELD FORT RUCKER	3769.48	3365.93	20642.88	492.83
722270TYA.CSV	MARIETTA DOBBINS AFB	3663.70	2794.72	23832.05	492.83
722280TYA.CSV	BIRMINGHAM MUNICIPAL AP	3594.49	3024.71	20529.92	495.05
722284TYA.CSV	AUBURN-OPELIKA APT	3527.16	2838.06	20936.94	492.83
722285TYA.CSV	GADSEN MUNI (AWOS)	3497.03	2753.56	21162.36	495.05
722286TYA.CSV	TUSCALOOSA MUNICIPAL AP	3676.21	3196.53	20463.19	492.83
722287TYA.CSV	ANNISTON METROPOLITAN AP	3583.93	3042.23	20183.66	495.05
722310TYA.CSV	NEW ORLEANS INTL ARPT	3475.08	3791.17	17334.75	409.33
722314TYA.CSV	NEW IBERIA NAAS	4043.46	3672.45	18375.39	409.33
722315TYA.CSV	NEW ORLEANS LAKEFRONT AP	3518.52	3897.25	17336.64	409.33
722316TYA.CSV	NEW ORLEANS ALVIN CALLENDER F	3427.71	3731.91	16922.65	409.33
722317TYA.CSV	BATON ROUGE RYAN ARPT	3434.35	3545.68	18423.10	409.33
722329TYA.CSV	PATTERSON MEMORIAL	3923.72	3517.37	17758.25	559.25
722340TYA.CSV	MERIDIAN KEY FIELD	3655.17	3177.04	20135.38	495.05
722345TYA.CSV	MERIDIAN NAAS	3669.28	3267.25	19580.29	495.05
722348TYA.CSV	HATTIESBURG LAUREL	3600.21	3114.76	19801.26	492.83
722350TYA.CSV	JACKSON INTERNATIONAL AP	3393.45	3240.09	19947.01	495.05
722356TYA.CSV	GREENVILLE MUNICIPAL	3350.28	3203.89	19427.12	409.33
722357TYA.CSV	NATCHEZ/HARDY(AWOS)	3314.00	3238.53	18492.88	492.83
722358TYA.CSV	MCCOMB PIKE COUNTY AP	3479.40	3505.28	19531.26	409.33
722359TYA.CSV	GREENWOOD LEFLORE ARPT	3405.71	3224.20	20275.26	409.33
722390TYA.CSV	FORT POLK AAF	3517.95	3510.46	20187.77	409.33
722400TYA.CSV	LAKE CHARLES REGIONAL ARPT	3491.24	3727.62	18100.46	409.33
722404TYA.CSV	LAKE CHARLES WB AIRP	3538.47	3700.91	19126.41	409.33
722405TYA.CSV	LAFAYETTE REGIONAL AP	4031.17	3664.26	18242.85	409.33
722406TYA.CSV	HOUMA-TERREBONNE	3585.59	3806.82	19188.41	409.33
722410TYA.CSV	PORT ARTHUR JEFFERSON COUNTY	3516.37	3854.82	17610.70	409.33

722420TYA.CSV	GALVESTON/SCHOLES	3723.93	4075.69	16963.16	446.34
722429TYA.CSV	HOUSTON/D.W. HOOKS	3703.46	3902.31	17990.12	409.33
722430TYA.CSV	HOUSTON BUSH INTERCONTINENTAL	3603.55	3693.46	17871.73	446.34
722435TYA.CSV	HOUSTON WILLIAM P HOBBY AP	3546.04	3767.32	16236.94	446.34
722436TYA.CSV	HOUSTON ELLINGTON AFB [CLEAR LAKE - UT]	3688.35	3836.64	18221.31	446.34
722445TYA.CSV	COLLEGE STATION EASTERWOOD FL	3545.22	3526.00	18171.51	446.34
722446TYA.CSV	LUFKIN ANGELINA CO	3417.12	3462.86	18720.04	409.33
722448TYA.CSV	TYLER/POUNDS FLD	3493.02	3220.55	19690.99	446.34
722470TYA.CSV	LONGVIEW GREGG COUNTY AP [OVERTON - UT]	3803.59	3172.62	19099.16	559.25
722480TYA.CSV	SHREVEPORT REGIONAL ARPT	3941.02	3333.93	19956.02	409.33
722484TYA.CSV	SHREVEPORT DOWNTOWN	3947.89	3287.66	20534.26	559.25
722485TYA.CSV	BARKSDALE AFB	3981.68	3305.12	20979.75	559.25
722486TYA.CSV	MONROE REGIONAL AP	3411.25	3347.15	19470.81	409.33
722487TYA.CSV	ALEXANDRIA ESLER REGIONAL AP	4022.03	3548.85	19246.96	559.25
722499TYA.CSV	NACOGDOCHES (AWOS)	3523.88	3235.53	20095.32	446.34
722500TYA.CSV	BROWNSVILLE S PADRE ISL INTL	3843.23	4382.70	16631.65	446.34
722505TYA.CSV	HARLINGEN RIO GRANDE VALLEY I	3795.72	4335.37	16156.11	446.34
722506TYA.CSV	MCALLEN MILLER INTL AP [EDINBURG - UT]	3719.92	4148.35	16294.29	446.34
722510TYA.CSV	CORPUS CHRISTI INTL ARPT [UT]	3744.66	4125.99	16926.23	446.34
722515TYA.CSV	CORPUS CHRISTI NAS	3876.92	4514.11	16182.04	446.34
722516TYA.CSV	KINGSVILLE	3691.20	4043.72	16620.76	446.34
722517TYA.CSV	ALICE INTL AP	3761.86	4143.77	17085.35	446.34
722520TYA.CSV	LAREDO INTL AP [UT]	3492.44	3527.86	17176.05	446.34
722523TYA.CSV	SAN ANTONIO/STINSON	3556.56	3543.75	18226.41	446.34
722524TYA.CSV	ROCKPORT/ARANSAS CO	3898.06	4502.77	16652.57	446.34
722526TYA.CSV	COTULLA FAA AP	3571.35	3772.01	16648.58	446.34
722530TYA.CSV	SAN ANTONIO INTL AP	3551.62	3539.50	18173.86	446.34
722533TYA.CSV	HONDO MUNICIPAL AP	3545.06	3489.86	18459.23	446.34
722535TYA.CSV	SAN ANTONIO KELLY FIELD AFB	3563.28	3537.97	18390.06	446.34
722536TYA.CSV	RANDOLPH AFB	3566.61	3466.26	19033.50	446.34
722540TYA.CSV	AUSTIN MUELLER MUNICIPAL AP [UT]	3553.97	3632.51	17466.23	446.34
722544TYA.CSV	CAMP MABRY	3550.94	3483.17	18619.21	446.34
722547TYA.CSV	GEORGETOWN (AWOS)	3384.45	3023.64	19277.32	446.34
722550TYA.CSV	VICTORIA REGIONAL AP	3651.64	3848.96	17487.17	446.34
722555TYA.CSV	PALACIOS MUNICIPAL AP	3804.95	4099.06	18236.61	446.34
722560TYA.CSV	WACO REGIONAL AP	3504.75	3271.76	19494.31	446.34
722563TYA.CSV	MC GREGOR (AWOS)	3415.22	3033.77	19776.97	446.34
722570TYA.CSV	FORT HOOD	3495.07	3231.83	19626.00	446.34
722575TYA.CSV	KILLEEN MUNI (AWOS)	3436.97	3083.61	19763.13	446.34
722576TYA.CSV	ROBERT GRAY AAF	3405.09	3130.78	18819.19	446.34
722577TYA.CSV	DRAUGHON MILLER CEN	3521.59	3235.19	20048.68	446.34
722583TYA.CSV	DALLAS LOVE FIELD	3571.07	3369.39	19889.72	446.34

722587TYA.CSV	COX FLD	3480.12	2912.62	21896.67	446.34
722588TYA.CSV	GREENVILLE/MAJORS	3557.58	3174.17	21182.53	446.34
722590TYA.CSV	DALLAS-FORT WORTH INTL AP	3513.03	3225.36	20015.66	446.34
722594TYA.CSV	FORT WORTH ALLIANCE	3572.28	3194.75	21326.30	446.34
722595TYA.CSV	FORT WORTH NAS	3409.94	3121.73	18986.52	446.34
722596TYA.CSV	FORT WORTH MEACHAM	3549.70	3242.17	20538.83	446.34
722597TYA.CSV	MINERAL WELLS MUNICIPAL AP	3446.80	3053.97	20194.34	446.34
722598TYA.CSV	DALLAS/ADDISON ARPT	3514.61	3091.02	21085.79	446.34
722599TYA.CSV	DALLAS/REDBIRD ARPT	3482.92	3272.55	19073.12	446.34
722610TYA.CSV	DEL RIO [UT]	3426.62	3387.09	17145.29	446.34
722615TYA.CSV	DEL RIO LAUGHLIN AFB	3437.23	3566.08	15881.37	446.34
722630TYA.CSV	SAN ANGELO MATHIS FIELD	3277.80	2741.23	19673.88	446.34
722636TYA.CSV	DALHART MUNICIPAL AP	3731.63	2144.68	28180.35	559.25
722640TYA.CSV	MARFA AP	3188.05	2133.74	22906.17	446.34
722650TYA.CSV	MIDLAND INTERNATIONAL AP	3170.61	2490.83	19761.68	446.34
722656TYA.CSV	WINK WINKLER COUNTY AP	3261.39	2719.23	19538.66	446.34
722660TYA.CSV	ABILENE REGIONAL AP [UT]	3306.13	2657.29	20861.71	446.34
722670TYA.CSV	LUBBOCK INTERNATIONAL AP	3599.55	2422.67	22991.27	559.25
722680TYA.CSV	ROSWELL INDUSTRIAL AIR PARK	3493.24	2348.42	21828.03	489.61
722683TYA.CSV	SIERRA BLANCA RGNL	3541.74	2017.80	28593.43	489.61
722686TYA.CSV	CLOVIS CANNON AFB	3729.92	2336.61	26198.92	559.25
722687TYA.CSV	CARLSBAD CAVERN CITY AIR TERM	3514.74	2481.92	20844.24	559.25
722689TYA.CSV	CLOVIS MUNI (AWOS)	3615.01	2151.92	25927.94	559.25
722695TYA.CSV	LAS CRUCES INTL	3390.57	2418.91	22333.93	489.61
722700TYA.CSV	EL PASO INTERNATIONAL AP [UT]	3269.82	2388.13	20454.48	489.61
722710TYA.CSV	TRUTH OR CONSEQUENCES MUNI AP	3421.78	2251.20	24405.64	489.61
722725TYA.CSV	DEMING MUNI	3420.61	2355.34	23442.85	489.61
722735TYA.CSV	DOUGLAS BISBEE-DOUGLAS INTL A	3337.96	2426.71	21331.17	489.61
722740TYA.CSV	TUCSON INTERNATIONAL AP	3238.91	2648.33	17593.14	489.61
722745TYA.CSV	DAVIS MONTHAN AFB	3264.08	2797.87	16709.59	489.61
722747TYA.CSV	SAFFORD (AMOS)	3305.17	2581.68	19367.30	489.61
722748TYA.CSV	CASA GRANDA (AWOS)	3175.19	2716.22	15810.09	489.61
722780TYA.CSV	PHOENIX SKY HARBOR INTL AP	3164.06	2929.96	13732.51	489.61
722784TYA.CSV	DEER VALLEY/PHOENIX	3153.48	2767.58	14983.29	489.61
722785TYA.CSV	LUKE AFB	3263.42	3046.30	14497.66	489.61
722789TYA.CSV	SCOTTSDALE MUNI	3175.08	2813.90	14949.12	489.61
722800TYA.CSV	YUMA INTL ARPT	3164.96	2962.05	13464.00	489.61
722860TYA.CSV	MARCH AFB	2533.39	2337.91	18506.82	237.62
722868TYA.CSV	PALM SPRINGS INTL	2287.54	2738.85	12335.37	237.62
722869TYA.CSV	RIVERSIDE MUNI	2387.38	2286.06	16099.61	237.62
722880TYA.CSV	BURBANK-GLENDALE-PASSADENA AP	2370.90	2357.32	15498.11	237.62
722885TYA.CSV	SANTA MONICA MUNI	2332.28	2314.74	14991.47	237.62
722886TYA.CSV	VAN NUYS AIRPORT	2312.42	2317.65	14612.03	237.62

722895TYA.CSV	LOMPOC (AWOS)	2588.05	1875.24	21475.49	237.62
722897TYA.CSV	SAN LUIS CO RGNL	2357.65	1954.14	16996.48	237.62
722899TYA.CSV	CHINO AIRPORT	2375.19	2283.32	15891.02	237.62
722900TYA.CSV	SAN DIEGO LINDBERGH FIELD	2298.93	2410.09	13977.21	237.62
722903TYA.CSV	SAN DIEGO/MONTGOMER	2321.69	2255.20	15053.43	237.62
722904TYA.CSV	CHULA VISTA BROWN FIELD NAAS	2345.09	2212.95	15656.86	237.62
722906TYA.CSV	SAN DIEGO NORTH ISLAND NAS	2364.03	2458.51	14948.86	237.62
722926TYA.CSV	CAMP PENDLETON MCAS	2403.51	2257.12	16524.00	237.62
722927TYA.CSV	CARLSBAD/PALOMAR	2359.45	2264.65	15698.04	237.62
722930TYA.CSV	SAN DIEGO MIRAMAR NAS	2400.24	2323.79	16174.92	237.62
722950TYA.CSV	LOS ANGELES INTL ARPT	2300.94	2306.90	14459.20	237.62
722956TYA.CSV	JACK NORTHROP FLD H	2306.44	2274.43	14697.21	237.62
722970TYA.CSV	LONG BEACH DAUGHERTY FLD	2282.84	2325.83	14048.74	237.62
722976TYA.CSV	FULLERTON MUNICIPAL	2328.64	2379.97	14640.93	237.62
722977TYA.CSV	SANTA ANA JOHN WAYNE AP	2321.37	2412.51	14373.66	237.62
723013TYA.CSV	WILMINGTON INTERNATIONAL ARPT	3185.54	3195.61	19628.06	356.47
723030TYA.CSV	FAYETTEVILLE POPE AFB	3214.70	2838.30	22457.61	356.47
723035TYA.CSV	FAYETTEVILLE RGNL G	3236.15	2808.67	23032.43	356.47
723040TYA.CSV	CAPE HATTERAS NWS BLDG	3180.40	3202.61	19489.62	356.47
723046TYA.CSV	DARE CO RGNL	3156.92	2949.27	20670.02	356.47
723060TYA.CSV	RALEIGH DURHAM INTERNATIONAL	3242.10	2876.07	22711.45	356.47
723065TYA.CSV	PITT GREENVILLE ARP	3112.70	2717.10	21355.47	356.47
723066TYA.CSV	GOLDSBORO SEYMOUR JOHNSON AFB	3269.19	2897.58	23058.66	356.47
723067TYA.CSV	KINSTON STALLINGS AFB	3271.96	2972.27	22596.10	356.47
723068TYA.CSV	ROCKY MOUNT WILSON	3093.44	2739.15	20897.15	356.47
723069TYA.CSV	JACKSONVILLE (AWOS)	3295.10	2821.69	23974.46	356.47
723075TYA.CSV	OCEANA NAS	3190.59	2941.73	21357.93	356.47
723080TYA.CSV	NORFOLK INTERNATIONAL AP	3182.34	2837.64	21877.89	356.47
723083TYA.CSV	FRANKLIN NAAS	3152.08	2832.53	21327.00	356.47
723085TYA.CSV	NORFOLK NAS	3117.12	2865.43	20519.28	356.47
723086TYA.CSV	NEWPORT NEWS	3223.74	2904.79	22188.83	356.47
723090TYA.CSV	CHERRY POINT MCAS	3281.53	3012.21	22543.36	356.47
723095TYA.CSV	NEW BERN CRAVEN CO REGL AP	3160.63	3192.81	19198.37	356.47
723096TYA.CSV	NEW RIVER MCAF	3274.90	3161.31	21464.01	356.47
723100TYA.CSV	COLUMBIA METRO ARPT	3180.30	3069.57	20342.90	356.47
723106TYA.CSV	FLORENCE REGIONAL AP	3209.00	3242.80	19737.02	356.47
723110TYA.CSV	ATHENS BEN EPPS AP	3554.62	2917.85	20763.56	492.83
723119TYA.CSV	GREENVILLE DOWNTOWN AP	3249.66	2747.93	23667.97	356.47
723120TYA.CSV	GREER GREENV'L-SPARTANBRG AP	3148.07	2750.47	21823.95	356.47
723125TYA.CSV	ANDERSON COUNTY AP	3219.57	2809.70	22727.68	356.47
723140TYA.CSV	CHARLOTTE DOUGLAS INTL ARPT	3159.67	2806.78	21669.29	356.47
723143TYA.CSV	SOUTHERN PINES AWOS	3106.69	2514.21	22552.21	356.47
723145TYA.CSV	HICKORY REGIONAL AP	3166.71	2671.37	22665.72	356.47

723150TYA.CSV	ASHEVILLE REGIONAL ARPT	3230.75	2498.02	24954.37	356.47
723170TYA.CSV	GREENSBORO PIEDMONT TRIAD INT	3246.20	2725.13	23757.92	356.47
723183TYA.CSV	BRISTOL TRI CITY AIRPORT	3558.95	2453.94	24884.56	495.05
723193TYA.CSV	WINSTON-SALEM REYNOLDS AP	3139.27	2713.66	21892.28	356.47
723200TYA.CSV	ROME R B RUSSELL AP	3647.61	2905.02	22532.60	492.83
723230TYA.CSV	HUNTSVILLE INTL/JONES FIELD	3617.46	2855.52	22339.22	495.05
723235TYA.CSV	MUSCLE SHOALS REGIONAL AP	3589.49	3026.44	20301.52	495.05
723240TYA.CSV	CHATTANOOGA LOVELL FIELD AP	3626.93	2915.19	21973.51	495.05
723260TYA.CSV	KNOXVILLE MCGHEE TYSON AP	3646.89	2757.84	23741.27	495.05
723265TYA.CSV	CROSSVILLE MEMORIAL AP	3538.07	2585.60	23312.15	495.05
723270TYA.CSV	NASHVILLE INTERNATIONAL AP	3672.88	2865.73	23242.39	495.05
723300TYA.CSV	POPLAR BLUFF(AMOS)	3952.30	2937.26	24168.89	799.61
723306TYA.CSV	COLUMBUS AFB	3770.95	3125.90	22678.85	495.05
723307TYA.CSV	GOLDEN TRI(AWOS)	3729.52	3012.24	22895.64	495.05
723320TYA.CSV	TUPELO C D LEMONS ARPT	3587.77	2972.58	20750.44	495.05
723340TYA.CSV	MEMPHIS INTERNATIONAL AP	3640.06	3016.87	21295.68	495.05
723346TYA.CSV	JACKSON MCKELLAR-SIPES REGL A	3554.80	2814.12	21578.10	495.05
723347TYA.CSV	DYERSBURG MUNICIPAL AP	3650.98	2829.79	23106.10	495.05
723403TYA.CSV	LITTLE ROCK ADAMS FIELD	3467.58	3128.08	22115.61	409.33
723405TYA.CSV	LITTLE ROCK AFB	3535.37	3147.88	23192.68	409.33
723406TYA.CSV	WALNUT RIDGE (AWOS)	3837.07	2824.16	23171.84	409.33
723407TYA.CSV	JONESBORO MUNI	3981.95	2951.36	24551.04	409.33
723415TYA.CSV	MEMORIAL FLD	3445.36	3088.44	22002.31	409.33
723416TYA.CSV	STUTTGART (AWOS)	3420.37	3163.45	20959.78	409.33
723417TYA.CSV	PINE BLUFF FAA AP	3596.99	3337.03	22880.53	409.33
723418TYA.CSV	TEXARKANA WEBB FIELD	3428.60	3326.48	19936.16	409.33
723419TYA.CSV	EL DORADO GOODWIN FIELD	3484.32	3368.14	20632.30	409.33
723434TYA.CSV	SPRINGDALE MUNI	3795.24	2677.03	23885.77	559.25
723440TYA.CSV	FORT SMITH REGIONAL AP	3487.58	3008.54	23359.08	559.25
723443TYA.CSV	SILOAM SPRING(AWOS)	3749.71	2662.46	23224.39	559.25
723444TYA.CSV	BENTONVILLE (AWOS)	3897.06	2726.03	25232.68	559.25
723445TYA.CSV	FAYETTEVILLE DRAKE FIELD	3866.14	2884.77	23144.60	559.25
723446TYA.CSV	HARRISON FAA AP	3833.46	2783.13	23579.94	409.33
723447TYA.CSV	FLIPPIN (AWOS)	3307.72	2613.53	22990.14	409.33
723448TYA.CSV	BATESVILLE (AWOS)	3348.97	2685.55	23189.65	409.33
723449TYA.CSV	ROGERS (AWOS)	3854.10	2670.23	25021.68	559.25
723489TYA.CSV	CAPE GIRARDEAU MUNICIPAL AP	4541.98	2738.57	24731.34	799.61
723495TYA.CSV	JOPLIN MUNICIPAL AP	3838.93	2858.58	22942.41	799.61
723510TYA.CSV	WICHITA FALLS MUNICIPAL ARPT	3396.37	2861.06	20839.35	446.34
723520TYA.CSV	ALTUS AFB	3726.29	2767.48	21779.44	559.25
723525TYA.CSV	HOBART MUNICIPAL AP	3768.66	2752.42	22712.81	559.25
723526TYA.CSV	CLINTON-SHERMAN	3850.62	2720.57	24505.74	559.25
723527TYA.CSV	GAGE AIRPORT	4411.31	2571.78	24718.25	559.25

723530TYA.CSV	OKLAHOMA CITY WILL ROGERS WOR	3783.46	2775.13	22752.12	559.25
723535TYA.CSV	VANCE AFB	3797.61	2578.34	24992.03	559.25
723540TYA.CSV	OKLAHOMA CITY TINKER AFB	3898.63	2839.66	24180.66	559.25
723544TYA.CSV	OKLAHOMA CITY/WILEY	3828.54	2740.32	23917.18	559.25
723545TYA.CSV	STILLWATER RGNL	3878.55	2891.52	23268.77	559.25
723546TYA.CSV	PONCA CITY MUNICIPAL AP [SGP - ARM]	3880.12	2886.37	23357.10	559.25
723550TYA.CSV	FORT SILL POST FIELD AF	3717.00	2717.65	22118.99	559.25
723560TYA.CSV	TULSA INTERNATIONAL AIRPORT	3949.36	2946.93	24024.26	559.25
723565TYA.CSV	BARTLESVILLE/PHILLI	3837.04	2670.98	24760.05	559.25
723566TYA.CSV	MCALESTER MUNICIPAL AP	3554.05	3092.42	21828.80	559.25
723575TYA.CSV	LAWTON MUNICIPAL	3795.28	2919.63	21504.45	559.25
723600TYA.CSV	CLAYTON MUNICIPAL AIRPARK	3532.00	2087.30	27843.37	489.61
723604TYA.CSV	CHILDRESS MUNICIPAL AP	3313.26	2581.00	21600.83	446.34
723627TYA.CSV	GALLUP SEN CLARKE FLD	3801.61	1991.77	33591.01	306.55
723630TYA.CSV	AMARILLO INTERNATIONAL AP [CANYON - UT]	3632.91	2270.06	25155.27	559.25
723650TYA.CSV	ALBUQUERQUE INTL ARPT [ISIS]	3487.02	2085.44	27075.00	489.61
723656TYA.CSV	SATA FE COUNTY MUNICIPAL AP	3680.99	1988.62	31405.71	489.61
723658TYA.CSV	FARMINGTON FOUR CORNERS REGL	3717.12	2136.86	30745.31	306.55
723663TYA.CSV	TAOS MUNI APT(AWOS)	4021.21	1928.69	38003.11	489.61
723676TYA.CSV	TUCUMCARI FAA AP	3606.30	2210.46	25272.33	559.25
723677TYA.CSV	LAS VEGAS MUNICIPAL ARPT	3699.48	1954.11	32035.46	489.61
723700TYA.CSV	KINGMAN (AMOS)	3437.67	2502.11	22459.04	489.61
723710TYA.CSV	PAGE MUNI (AMOS)	3807.00	2338.08	25354.75	306.55
723723TYA.CSV	PRESCOTT LOVE FIELD	3523.01	2115.82	27450.96	489.61
723740TYA.CSV	WINSLOW MUNICIPAL AP	3623.18	2188.94	28607.07	306.55
723747TYA.CSV	SHOW LOW MUNICIPAL	3614.56	2000.88	30070.14	489.61
723755TYA.CSV	FLAGSTAFF PULLIAM ARPT	3942.43	1881.73	37115.15	489.61
723783TYA.CSV	GRAND CANYON NATL P	3976.38	1994.79	36673.82	489.61
723805TYA.CSV	NEEDLES AIRPORT	2442.13	2923.53	14331.39	237.62
723810TYA.CSV	EDWARDS AFB	2767.04	2351.90	22660.59	237.62
723815TYA.CSV	DAGGETT BARSTOW-DAGGETT AP	2522.72	2463.71	17768.64	237.62
723816TYA.CSV	LANCASTER GEN WM FOX FIELD	2633.71	2288.16	20523.15	237.62
723820TYA.CSV	PALMDALE AIRPORT	2680.95	2281.39	21405.36	237.62
723830TYA.CSV	SANDBERG	2785.08	1978.83	24597.42	237.62
723840TYA.CSV	BAKERSFIELD MEADOWS FIELD	2312.44	2242.31	14932.44	237.62
723860TYA.CSV	LAS VEGAS MCCARRAN INTL AP	3382.78	2658.16	20107.17	489.61
723865TYA.CSV	NELLIS AFB	3431.87	2898.12	18853.96	489.61
723870TYA.CSV	MERCURY DESERT ROCK AP [SURFRAD]	2979.45	2481.81	22777.07	489.61
723890TYA.CSV	FRESNO YOSEMITE INTL AP	2300.94	2198.87	14912.42	237.62
723895TYA.CSV	PORTERVILLE (AWOS)	2402.51	2117.83	17077.24	237.62
723896TYA.CSV	VISALIA MUNI (AWOS)	2502.23	2184.81	18594.34	237.62
723910TYA.CSV	POINT MUGU NF	2390.58	2181.11	16618.63	237.62

723925TYA.CSV	SANTA BARBARA MUNICIPAL AP	2393.57	2143.66	16832.56	237.62
723926TYA.CSV	CAMARILLO (AWOS)	2380.16	2131.98	16636.66	237.62
723927TYA.CSV	OXNARD AIRPORT	2385.47	2189.78	16489.62	237.62
723940TYA.CSV	SANTA MARIA PUBLIC ARPT	2398.55	1914.25	17904.30	237.62
723965TYA.CSV	PASO ROBLES MUNICIPAL ARPT	2465.32	2038.34	18574.67	237.62
724010TYA.CSV	RICHMOND INTERNATIONAL AP	3233.69	2735.76	23463.71	356.47
724014TYA.CSV	DINWIDDIE CO	3257.02	2928.11	22592.24	356.47
724016TYA.CSV	CHARLOTTESVILLE FAA	3172.71	2570.94	23408.72	356.47
724017TYA.CSV	FARMVILLE	3219.78	2613.71	23949.23	559.86
724026TYA.CSV	MELFA/ACCOMACK ARPT	3203.32	2808.93	23079.42	343.34
724030TYA.CSV	WASHINGTON DC DULLES INT'L AR [STERLING - ISIS]	3318.38	2550.82	26188.63	356.47
724033TYA.CSV	SHANNON ARPT	3320.11	2621.72	25705.86	356.47
724035TYA.CSV	QUANTICO MCAS	3197.17	2683.35	23795.15	356.47
724036TYA.CSV	MANASSAS MUNI(AWOS)	3348.28	2431.90	27435.61	356.47
724037TYA.CSV	DAVISON AAF	3356.79	2712.31	25837.98	356.47
724040TYA.CSV	PATUXENT RIVER NAS	3167.39	2881.82	22024.28	343.34
724045TYA.CSV	SALISBURY WICOMICO CO AP	3164.25	2721.75	22956.96	343.34
724050TYA.CSV	WASHINGTON DC REAGAN AP	3213.62	2653.06	24276.19	356.47
724053TYA.CSV	WINCHESTER RGNL	3309.82	2398.76	26948.03	356.47
724055TYA.CSV	LEESBURG/GODFREY	3349.45	2467.69	27220.07	356.47
724056TYA.CSV	MARION / WYTHEVILLE	3681.34	2232.10	26321.59	559.86
724058TYA.CSV	ABINGTON	3698.12	2284.72	26069.15	559.86
724060TYA.CSV	BALTIMORE BLT-WASHNGTN INT'L	3241.10	2531.69	25520.89	343.34
724066TYA.CSV	HAGERSTOWN RGNL RIC	3802.85	2452.73	26320.92	559.86
724070TYA.CSV	ATLANTIC CITY INTL AP	3242.93	2449.01	26075.63	343.34
724075TYA.CSV	MILLVILLE MUNICIPAL AP	3261.52	2625.45	25317.72	343.34
724080TYA.CSV	PHILADELPHIA INTERNATIONAL AP	3243.52	2494.29	25802.23	343.34
724084TYA.CSV	BELMAR ASC	3213.75	2232.99	26830.88	343.34
724085TYA.CSV	PHILADELPHIA NE PHILADELPHIA	3220.33	2494.42	25373.89	343.34
724086TYA.CSV	WILLOW GROVE NAS	3184.99	2403.59	25311.97	343.34
724088TYA.CSV	DOVER AFB	3273.42	2506.78	26267.98	343.34
724089TYA.CSV	WILMINGTON NEW CASTLE CNTY AP	3289.04	2496.77	26611.29	343.34
724094TYA.CSV	CALDWELL/ESSEX CO.	3188.58	2262.28	26245.53	343.34
724095TYA.CSV	TRENTON MERCER COUNTY AP	3274.31	2510.40	26262.53	343.34
724096TYA.CSV	MCGUIRE AFB	3260.51	2461.66	26314.23	343.34
724100TYA.CSV	LYNCHBURG REGIONAL ARPT	3786.84	2592.70	24644.55	559.86
724105TYA.CSV	STAUNTON/SHENANDOAH	3859.71	2523.19	26591.58	559.86
724106TYA.CSV	DANVILLE FAA AP	3241.41	2810.80	23110.24	559.86
724107TYA.CSV	HILLSVILLE	3842.17	2319.96	28317.93	559.86
724110TYA.CSV	ROANOKE REGIONAL AP	3713.89	2494.63	24332.28	559.86
724113TYA.CSV	VIRGINIA TECH ARPT	3788.66	2317.74	27392.83	559.86
724115TYA.CSV	HOT SPRINGS/INGALLS	3394.75	2010.52	30996.91	356.47

724116TYA.CSV	PULASKI	3704.23	2195.03	27168.92	559.86
724117TYA.CSV	WISE/LONESOME PINE	3741.77	2311.76	26597.38	559.86
724120TYA.CSV	BECKLEY RALEIGH CO MEM AP	3813.59	2341.92	27668.52	559.86
724125TYA.CSV	BLUEFIELD/MERCER CO [NREL]	3650.51	2261.82	25539.86	559.86
724127TYA.CSV	LEWISBURG/GREENBRIE	3880.20	2242.67	29775.39	559.86
724140TYA.CSV	CHARLESTON YEAGER ARPT	3829.71	2563.90	25724.42	559.86
724170TYA.CSV	ELKINS ELKINS-RANDOLPH CO ARP	3857.77	2254.90	29379.02	559.86
724175TYA.CSV	HARRISON MARION RGN	3786.02	2401.91	26549.47	559.86
724176TYA.CSV	MORGANTOWN HART FIELD	3731.46	2356.90	26046.74	559.86
724177TYA.CSV	MARTINSBURG EASTERN WV REG AP	3674.46	2408.53	24486.41	559.86
724210TYA.CSV	CINCINNATI NORTHERN KY AP	3817.03	2436.87	26769.80	495.05
724220TYA.CSV	LEXINGTON BLUEGRASS AP	3728.21	2638.82	26273.79	495.05
724230TYA.CSV	LOUISVILLE STANDIFORD FIELD	3717.79	2714.08	25413.51	495.05
724235TYA.CSV	LOUISVILLE BOWMAN FIELD	3685.33	2809.58	23948.37	495.05
724236TYA.CSV	JACKSON JULIAN CARROLL AP	3534.39	2543.37	23631.83	495.05
724238TYA.CSV	HENDERSON CITY	3527.44	2281.14	25765.73	495.05
724240TYA.CSV	FORT KNOX GODMAN AAF	3664.66	2555.78	25868.61	495.05
724243TYA.CSV	LONDON-CORBIN AP	3608.72	2556.56	24833.79	495.05
724250TYA.CSV	HUNTINGTON TRI-STATE ARPT	3816.97	2550.86	25620.53	559.86
724273TYA.CSV	PARKERSBURG WOOD COUNTY AP	3878.85	2561.14	26620.49	559.86
724275TYA.CSV	WHEELING OHIO COUNTY AP	3830.65	2297.01	28413.41	559.86
724280TYA.CSV	COLUMBUS PORT COLUMBUS INTL A	3800.47	2340.88	27456.80	559.86
724286TYA.CSV	ZANESVILLE MUNICIPAL AP	3735.54	2385.87	25820.11	559.86
724288TYA.CSV	OHIO STATE UNIVERSI	3880.87	2543.75	26837.64	559.86
724290TYA.CSV	DAYTON INTERNATIONAL AIRPORT	3927.58	2428.03	28853.42	559.86
724297TYA.CSV	CINCINNATI MUNICIPAL AP LUNKI	3823.52	2533.85	25907.23	495.05
724320TYA.CSV	EVANSVILLE REGIONAL AP	3840.40	2668.49	24836.14	559.86
724335TYA.CSV	MOUNT VERNON (AWOS)	4509.79	2612.57	25820.34	799.61
724336TYA.CSV	SOUTHERN ILLINOIS	4711.55	2922.07	25092.32	799.61
724338TYA.CSV	BELLEVILLE SCOTT AFB	4543.89	2558.96	27333.00	799.61
724339TYA.CSV	MARION REGIONAL	4472.11	2623.38	24995.62	799.61
724340TYA.CSV	ST LOUIS LAMBERT INT'L ARPT	4441.97	2553.64	25544.35	799.61
724345TYA.CSV	ST LOUIS SPIRIT OF ST LOUIS A	4420.23	2605.07	24436.71	799.61
724350TYA.CSV	PADUCAH BARKLEY REGIONAL AP	3606.96	2777.41	22837.18	495.05
724354TYA.CSV	SOMERSET(AWOS)	3582.96	2634.26	23620.97	495.05
724365TYA.CSV	HUNTINGBURG	3802.20	2666.16	24104.71	559.86
724373TYA.CSV	TERRE HAUTE HULMAN REGIONAL A	3960.32	2684.70	26849.97	559.86
724375TYA.CSV	MONROE CO	3978.61	2663.95	27334.66	799.61
724380TYA.CSV	INDIANAPOLIS INTL AP	3959.01	2497.83	28730.36	559.86
724386TYA.CSV	LAFAYETTE PURDUE UNIV AP	3972.52	2515.04	28772.62	559.86
724390TYA.CSV	SPRINGFIELD CAPITAL AP	4556.51	2541.58	27831.50	799.61
724396TYA.CSV	QUINCY MUNI BALDWIN FLD	4488.71	2538.29	26664.33	799.61
724397TYA.CSV	CENTRAL ILLINOIS RG	4447.17	2299.05	29188.34	799.61

724400TYA.CSV	SPRINGFIELD REGIONAL ARPT	3821.17	2571.02	25509.66	558.71
724450TYA.CSV	COLUMBIA REGIONAL AIRPORT	4519.87	2541.21	27158.64	799.61
724454TYA.CSV	FARMINGTON	4413.58	2532.05	25245.89	799.61
724455TYA.CSV	KIRKSVILLE REGIONAL AP	4769.24	2620.03	30546.46	799.61
724456TYA.CSV	VICHY ROLLA NATL ARPT	4400.01	2518.76	25342.93	799.61
724457TYA.CSV	FT LNRD WD AAF	4520.91	2635.26	25816.03	799.61
724458TYA.CSV	JEFFERSON CITY MEM	4601.85	2777.88	25203.03	799.61
724459TYA.CSV	KAISER MEM (AWOS)	4604.50	2736.01	25750.85	799.61
724460TYA.CSV	KANSAS CITY INT'L ARPT	3979.02	2598.48	28107.34	558.71
724463TYA.CSV	KANSAS CITY DOWNTOWN AP	3983.02	2922.49	24895.63	558.71
724467TYA.CSV	WHITEMAN AFB	4446.55	2523.02	26087.28	799.61
724468TYA.CSV	OLATHE/JOHNSON CO.	3888.47	2676.21	25676.66	558.71
724475TYA.CSV	OLATHE JOHNSON CO INDUSTRIAL	3963.05	2718.06	26590.40	558.71
724490TYA.CSV	ST JOSEPH ROSECRANS MEMORIAL	4059.40	2689.72	28605.24	558.71
724500TYA.CSV	WICHITA MID-CONTINENT AP	3760.54	2540.72	24746.67	558.71
724504TYA.CSV	WICHITA/COL. JABARA	3868.31	2617.03	25913.37	558.71
724505TYA.CSV	MCCONNELL AFB	3761.73	2494.57	25214.25	558.71
724506TYA.CSV	HUTCHINSON MUNICIPAL AP	3853.65	2616.63	25648.86	558.71
724507TYA.CSV	CHANUTE MARTIN JOHNSON AP	4031.12	2928.34	25710.47	558.71
724509TYA.CSV	NEWTON (AWOS)	3839.59	2476.66	26713.28	558.71
724510TYA.CSV	DODGE CITY REGIONAL AP	3792.71	2347.99	27277.69	558.71
724515TYA.CSV	GARDEN CITY MUNICIPAL AP	3869.69	2366.40	28454.83	558.71
724516TYA.CSV	LIBERAL MUNI	3816.02	2448.84	26587.93	558.71
724517TYA.CSV	GREAT BEND (AWOS)	3766.94	2345.33	26752.75	558.71
724518TYA.CSV	HAYS MUNI (AWOS)	3709.98	2267.06	26507.09	558.71
724550TYA.CSV	FORT RILEY MARSHALL AAF	3853.25	2643.65	25361.72	558.71
724555TYA.CSV	MANHATTAN RGNL	4024.05	2774.70	27112.49	558.71
724556TYA.CSV	EMPORIA MUNICIPAL AP	4101.30	2711.27	29165.38	558.71
724560TYA.CSV	TOPEKA MUNICIPAL AP	3928.05	2641.89	26757.16	558.71
724565TYA.CSV	TOPEKA FORBES FIELD	4007.60	2778.40	26789.33	558.71
724580TYA.CSV	CONCORDIA BLOSSER MUNI AP	3842.43	2511.45	26520.25	558.71
724585TYA.CSV	RUSSELL MUNICIPAL AP	3811.10	2411.63	26976.09	558.71
724586TYA.CSV	SALINA MUNICIPAL AP	3855.72	2608.32	25778.54	558.71
724620TYA.CSV	ALAMOSA SAN LUIS VALLEY RGNL	4421.79	1866.24	41762.33	610.83
724625TYA.CSV	DURANGO/LA PLATA CO	4141.26	1922.65	35977.58	610.83
724635TYA.CSV	LA JUNTA MUNICIPAL AP	3861.66	2149.69	28415.08	610.83
724636TYA.CSV	LAMAR MUNICIPAL	3962.73	2219.86	29464.88	610.83
724640TYA.CSV	PUEBLO MEMORIAL AP	3876.81	2124.38	29005.18	610.83
724645TYA.CSV	TRINIDAD LAS ANIMAS COUNTY AP	3904.56	2025.58	30540.53	610.83
724650TYA.CSV	GOODLAND RENNER FIELD	3817.43	2114.35	30096.56	558.71
724655TYA.CSV	HILL CITY MUNICIPAL AP	3896.67	2333.60	29295.38	558.71
724660TYA.CSV	COLORADO SPRINGS MUNI AP	4020.12	1967.53	33321.93	610.83
724665TYA.CSV	LIMON	4048.56	1981.09	33676.48	610.83

724666TYA.CSV	DENVER/CENTENNIAL [GOLDEN - NREL]	3943.36	1945.47	32158.23	610.83
724673TYA.CSV	LEADVILLE/LAKE CO.	4791.96	1784.75	49257.20	610.83
724675TYA.CSV	EAGLE COUNTY AP	4338.13	1917.15	39584.65	610.83
724676TYA.CSV	ASPEN PITKIN CO SAR	4431.15	1858.36	41927.91	610.83
724677TYA.CSV	GUNNISON CO. (AWOS)	4619.07	1838.16	45455.45	610.83
724695TYA.CSV	AURORA BUCKLEY FIELD ANGB	4038.23	2052.26	32667.43	610.83
724698TYA.CSV	AKRON WASHINGTON CO AP	3964.72	2051.28	31362.40	610.83
724699TYA.CSV	BROOMFIELD/JEFFCO [BOULDER - SURFRAD]	3924.35	1978.52	31490.99	610.83
724723TYA.CSV	BLANDING	3396.88	2130.92	32248.14	306.55
724735TYA.CSV	HANKSVILLE	3334.40	2335.87	29950.92	306.55
724754TYA.CSV	SAINT GEORGE (AWOS)	2945.51	2583.56	21582.60	306.55
724755TYA.CSV	CEDAR CITY MUNICIPAL AP	3384.55	2050.41	32503.60	306.55
724756TYA.CSV	BRYCE CNYN FAA AP	3927.74	1880.78	43224.30	306.55
724760TYA.CSV	GRAND JUNCTION WALKER FIELD	3924.56	2123.56	29853.02	610.83
724765TYA.CSV	MONTROSE CO. ARPT	4031.07	2049.40	32584.87	610.83
724767TYA.CSV	CORTEZ/MONTEZUMA CO	4072.43	2094.28	32820.24	610.83
724768TYA.CSV	GREELEY/WELD (AWOS)	4073.57	1962.25	34195.82	610.83
724769TYA.CSV	FORT COLLINS (AWOS)	4091.84	1954.83	34651.33	610.83
724776TYA.CSV	MOAB/CANYONLANDS [UO]	3265.29	2176.97	29613.02	306.55
724795TYA.CSV	DELTA	3353.05	2053.33	31890.22	306.55
724800TYA.CSV	BISHOP AIRPORT	3069.52	2326.94	28227.91	237.62
724815TYA.CSV	MERCED/MACREADY FLD	2355.00	2158.73	16058.90	237.62
724830TYA.CSV	SACRAMENTO EXECUTIVE ARPT	2395.25	2107.44	17010.21	237.62
724837TYA.CSV	BEALE AFB	2431.73	2208.83	17232.13	237.62
724838TYA.CSV	YUBA CO	2393.19	2182.29	16650.71	237.62
724839TYA.CSV	SACRAMENTO METROPOLITAN AP	2408.05	2159.18	17021.50	237.62
724855TYA.CSV	TONOPAH AIRPORT	3445.01	2122.55	33190.45	306.55
724860TYA.CSV	ELY YELLAND FIELD	3701.02	1960.53	38710.37	306.55
724880TYA.CSV	RENO TAHOE INTERNATIONAL AP	3310.78	2086.94	30970.02	306.55
724885TYA.CSV	FALLON NAAS	3291.62	2149.37	30249.25	306.55
724915TYA.CSV	MONTEREY NAF	2404.35	1911.57	18022.74	237.62
724917TYA.CSV	SALINAS MUNICIPAL AP	2392.99	1929.34	17745.29	237.62
724920TYA.CSV	STOCKTON METROPOLITAN ARPT	2357.38	2119.94	16273.02	237.62
724926TYA.CSV	MODESTO CITY-COUNTY AP	2294.26	2088.01	15269.27	237.62
724927TYA.CSV	LIVERMORE MUNICIPAL	2420.20	1967.22	18064.80	237.62
724930TYA.CSV	OAKLAND METROPOLITAN ARPT	2357.42	1987.56	16853.75	237.62
724935TYA.CSV	HAYWARD AIR TERM	2347.90	2045.82	16428.63	237.62
724936TYA.CSV	CONCORD CONCORD-BUCHANAN FIEL	2311.00	1945.26	16191.42	237.62
724940TYA.CSV	SAN FRANCISCO INTL AP	2315.65	1894.67	16497.82	237.62
724945TYA.CSV	SAN JOSE INTL AP	2338.33	1992.24	16486.21	237.62
724955TYA.CSV	NAPA CO. AIRPORT	2446.82	1995.96	18427.34	237.62
724957TYA.CSV	SANTA ROSA (AWOS)	2422.53	1989.34	18019.64	237.62

725020TYA.CSV	NEWARK INTERNATIONAL ARPT	3232.21	2408.44	26136.79	343.34
725025TYA.CSV	TETERBORO AIRPORT	3117.35	2212.77	25275.66	343.34
725029TYA.CSV	OXFORD (AWOS)	3204.98	2287.48	30223.85	251.58
725030TYA.CSV	NEW YORK LAGUARDIA ARPT	3034.12	2468.58	24839.20	285.06
725033TYA.CSV	NEW YORK CENTRAL PRK OBS BELV	3086.20	2438.61	25932.82	285.06
725035TYA.CSV	ISLIP LONG ISL MACARTHUR AP	3833.44	2496.72	26053.49	568.95
725036TYA.CSV	POUGHKEEPSIE DUTCHESS CO AP	2810.61	2336.47	28564.28	121.07
725037TYA.CSV	WHITE PLAINS WESTCHESTER CO A	3186.06	2282.88	28540.04	285.06
725038TYA.CSV	STEWART FIELD	2830.39	2237.19	29132.28	121.07
725040TYA.CSV	BRIDGEPORT SIKORSKY MEMORIAL	3061.00	2327.56	27490.44	251.58
725045TYA.CSV	NEW HAVEN TWEED AIRPORT	3044.29	2323.94	27188.37	251.58
725046TYA.CSV	GROTON NEW LONDON AP	3044.60	2295.35	27330.88	251.58
725054TYA.CSV	PAWTUCKET (AWOS)	3172.76	2166.82	30196.59	251.58
725058TYA.CSV	BLOCK ISLAND STATE ARPT	2998.02	2275.92	26548.12	251.58
725060TYA.CSV	OTIS ANGB	3102.92	2319.48	28290.49	251.58
725063TYA.CSV	NANTUCKET MEMORIAL AP	2934.02	2241.23	25582.83	251.58
725064TYA.CSV	PLYMOUTH MUNICIPAL	3035.18	2240.11	27419.17	251.58
725065TYA.CSV	NEW BEDFORD RGNL	3050.20	2286.80	27482.64	251.58
725066TYA.CSV	MARTHAS VINEYARD	3005.29	2279.41	26693.83	251.58
725067TYA.CSV	BARNSTABLE MUNI BOA	3005.34	2253.59	26825.38	251.58
725070TYA.CSV	PROVIDENCE T F GREEN STATE AR	3102.30	2281.36	28444.17	251.58
725073TYA.CSV	PROVINCETOWN (AWOS)	3014.74	2193.65	27219.80	251.58
725075TYA.CSV	NORTH ADAMS	3177.86	2139.12	30463.23	251.58
725080TYA.CSV	HARTFORD BRADLEY INTL AP	3139.69	2265.80	29195.32	251.58
725086TYA.CSV	DANBURY MUNICIPAL	3111.07	2233.97	28811.62	251.58
725087TYA.CSV	HARTFORD BRAINARD FD	3009.70	2221.84	27033.81	251.58
725088TYA.CSV	BEVERLY MUNI	3181.44	2164.34	30387.97	251.58
725090TYA.CSV	BOSTON LOGAN INT'L ARPT	3069.74	2216.37	28159.71	251.58
725095TYA.CSV	WORCHESTER REGIONAL ARPT	3280.73	2103.97	32483.89	251.58
725098TYA.CSV	NORWOOD MEMORIAL	3163.82	2342.10	29265.32	251.58
725103TYA.CSV	READING SPAATZ FIELD	3285.27	2487.63	26602.22	343.34
725115TYA.CSV	MIDDLETOWN HARRISBURG INTL AP	3432.91	2489.56	29251.04	343.34
725116TYA.CSV	LANCASTER	3210.40	2387.54	25866.85	343.34
725117TYA.CSV	WASHINGTON (AWOS)	3798.15	2242.73	28297.22	559.86
725118TYA.CSV	HARRISBURG CAPITAL CITY ARPT	3324.42	2428.02	27675.57	343.34
725124TYA.CSV	BUTLER CO. (AWOS)	3399.34	2180.75	30491.67	343.34
725125TYA.CSV	DUBOIS FAA AP	3436.02	2105.42	31646.93	343.34
725126TYA.CSV	ALTOONA BLAIR CO ARPT	3332.28	2273.37	28777.06	343.34
725127TYA.CSV	JOHNSTOWN CAMBRIA COUNTY AP	3437.93	2215.82	31019.43	343.34
725128TYA.CSV	STATE COLLEGE [PENN STATE - SURFRAD]	3358.78	2163.60	29879.05	343.34
725130TYA.CSV	WILKES-BARRE SCRANTON INTL AP	3349.39	2202.84	29521.46	343.34
725140TYA.CSV	WILLIAMSPORT REGIONAL AP	3334.13	2335.01	28430.64	343.34

725145TYA.CSV	MONTICELLO(AWOS)	2976.93	2107.09	32040.49	121.07
725150TYA.CSV	BINGHAMTON EDWIN A LINK FIELD	2951.65	2089.45	31650.85	121.07
725156TYA.CSV	ELMIRA CORNING REGIONAL AP	2876.17	2164.06	30121.57	121.07
725165TYA.CSV	RUTLAND STATE	3336.27	2123.65	33336.01	251.58
725170TYA.CSV	ALLENTOWN LEHIGH VALLEY INTL	3294.36	2286.03	28014.61	343.34
725180TYA.CSV	ALBANY COUNTY AP	2912.54	2177.47	30753.70	121.07
725185TYA.CSV	GLENS FALLS AP	2985.02	2251.79	31901.73	121.07
725190TYA.CSV	SYRACUSE HANCOCK INT'L ARPT	2878.22	2206.81	30066.98	121.07
725197TYA.CSV	UTICA ONEIDA COUNTY AP	2947.10	2198.26	31327.45	121.07
725200TYA.CSV	PITTSBURGH INTERNATIONAL AP	3821.98	2254.24	28732.01	559.86
725205TYA.CSV	PITTSBURGH ALLEGHENY CO AP	3732.41	2283.18	26784.44	559.86
725210TYA.CSV	AKRON AKRON-CANTON REG AP	3908.22	2298.61	29821.06	559.86
725235TYA.CSV	JAMESTOWN (AWOS)	2976.02	2035.50	32182.58	121.07
725240TYA.CSV	CLEVELAND HOPKINS INTL AP	3864.03	2300.06	29012.09	559.86
725245TYA.CSV	BURKE LAKEFRONT	3885.81	2352.44	28861.31	559.86
725246TYA.CSV	MANSFIELD LAHM MUNICIPAL ARPT	3969.55	2328.92	30621.40	559.86
725250TYA.CSV	YOUNGSTOWN REGIONAL AIRPORT	3930.63	2265.41	30578.21	559.86
725260TYA.CSV	ERIE INTERNATIONAL AP	3363.11	2204.73	29759.11	343.34
725266TYA.CSV	BRADFORD REGIONAL AP	3577.12	2031.15	34721.16	343.34
725267TYA.CSV	FRANKLIN	3372.53	2034.35	30927.65	343.34
725280TYA.CSV	BUFFALO NIAGARA INTL AP	2852.33	2095.77	29843.57	121.07
725287TYA.CSV	NIAGARA FALLS AF	2856.71	2224.77	29638.71	121.07
725290TYA.CSV	ROCHESTER GREATER ROCHESTER I	2878.58	2271.31	29933.46	121.07
725300TYA.CSV	CHICAGO OHARE INTL AP	3916.85	2323.80	29717.97	559.86
725305TYA.CSV	W. CHICAGO/DU PAGE	3861.51	2319.75	28737.75	559.86
725314TYA.CSV	CAHOKIA/ST. LOUIS	4592.83	2752.33	25387.55	799.61
725315TYA.CSV	UNIV OF ILLINOIS WI [BONDVILLE - SURFRAD]	4600.67	2570.43	28202.60	799.61
725316TYA.CSV	DECATUR	4608.24	2620.50	27612.75	799.61
725320TYA.CSV	PEORIA GREATER PEORIA AP	4508.59	2377.52	29342.80	799.61
725326TYA.CSV	STERLING ROCKFALLS	3855.43	2239.30	29356.60	559.86
725330TYA.CSV	FORT WAYNE INTL AP	3924.09	2302.29	30089.09	559.86
725335TYA.CSV	GRISSOM ARB	3836.89	2311.25	28399.87	559.86
725336TYA.CSV	DELAWARE CO JOHNSON	3868.76	2438.51	27661.29	559.86
725340TYA.CSV	CHICAGO MIDWAY AP	3818.36	2349.10	27672.37	559.86
725347TYA.CSV	CHICAGO/WAUKEGAN	3998.62	2311.16	31309.43	559.86
725350TYA.CSV	SOUTH BEND MICHIANA RGNL AP	3885.53	2383.20	28563.13	559.86
725360TYA.CSV	TOLEDO EXPRESS AIRPORT	3875.55	2230.68	29940.75	559.86
725366TYA.CSV	FINDLAY AIRPORT	3727.41	2222.59	27322.55	559.86
725370TYA.CSV	DETROIT METROPOLITAN ARPT	4110.93	2288.29	30622.78	630.04
725374TYA.CSV	ANN ARBOR MUNICIPAL	4052.52	2280.27	29622.77	630.04
725375TYA.CSV	DETROIT CITY AIRPORT	4055.25	2275.64	29762.21	630.04
725376TYA.CSV	DETROIT WILLOW RUN AP	4144.64	2355.97	30438.92	630.04

725377TYA.CSV	MOUNT CLEMENS SELFRIDGE FLD	3889.71	2156.66	28112.89	630.04
725378TYA.CSV	HOWELL	4116.40	2363.95	29734.64	630.04
725384TYA.CSV	ST.CLAIR COUNTY INT	4113.33	2334.45	30002.28	630.04
725390TYA.CSV	LANSING CAPITAL CITY ARPT	4119.62	2246.92	31246.79	630.04
725395TYA.CSV	JACKSON REYNOLDS FIELD	4108.19	2348.50	29878.06	630.04
725396TYA.CSV	BATTLE CREEK KELLOGG AP	4000.09	2230.43	29233.99	630.04
725430TYA.CSV	ROCKFORD GREATER ROCKFORD AP	4009.01	2272.98	31907.37	559.86
725440TYA.CSV	MOLINE QUAD CITY INTL AP	4094.50	2407.23	30500.34	595.71
725450TYA.CSV	CEDAR RAPIDS MUNICIPAL AP	4145.14	2414.44	31329.44	595.71
725453TYA.CSV	ATLANTIC	4242.57	2544.44	31578.35	595.71
725454TYA.CSV	WASHINGTON	4674.94	2537.97	29886.13	799.61
725455TYA.CSV	BURLINGTON MUNICIPAL AP	4708.35	2682.35	28544.91	595.71
725456TYA.CSV	KEOKUK MUNI	4056.75	2563.16	28018.29	595.71
725457TYA.CSV	ALGONA	4132.76	2292.32	32315.30	595.71
725460TYA.CSV	DES MOINES INTL AP	4157.47	2458.04	31082.79	595.71
725463TYA.CSV	CHARLES CITY	4157.34	2456.84	30979.77	595.71
725464TYA.CSV	NEWTON MUNI	4047.33	2425.61	29328.50	595.71
725465TYA.CSV	OTTUMWA INDUSTRIAL AP	4614.03	2417.99	30663.73	595.71
725467TYA.CSV	SHENANDOAH MUNI	4261.60	2678.70	30458.04	799.61
725468TYA.CSV	CARROLL	4198.20	2445.24	31828.94	595.71
725469TYA.CSV	CHARITON	4764.70	2659.28	29747.56	799.61
725470TYA.CSV	DUBUQUE REGIONAL AP	4163.30	2255.37	33406.05	595.71
725473TYA.CSV	CLINTON MUNI (AWOS)	4207.51	2455.70	31867.31	595.71
725474TYA.CSV	CRESTON	4181.84	2583.50	30069.34	595.71
725475TYA.CSV	MONTICELLO MUNI	4142.30	2402.79	31260.32	595.71
725476TYA.CSV	DECORAH	4077.41	2441.94	29699.75	595.71
725477TYA.CSV	DENISON	4188.93	2504.27	31037.63	595.71
725478TYA.CSV	WEBSTER CITY	4141.18	2496.30	30244.18	595.71
725479TYA.CSV	CLARINDA	4309.68	2814.92	29861.57	799.61
725480TYA.CSV	WATERLOO MUNICIPAL AP	4152.40	2308.25	32627.46	595.71
725483TYA.CSV	FORT MADISON	4576.84	2599.00	27239.89	799.61
725484TYA.CSV	LE MARS	4158.46	2575.00	29736.85	595.71
725485TYA.CSV	MASON CITY MUNICIPAL ARPT	4243.29	2300.51	34350.51	595.71
725486TYA.CSV	BOONE MUNI	4132.10	2422.95	30867.55	595.71
725487TYA.CSV	MUSCATINE	4154.96	2527.26	30181.65	595.71
725488TYA.CSV	OELWEN	4029.16	2334.64	29973.12	595.71
725489TYA.CSV	ORANGE CITY	4198.36	2442.23	31872.65	595.71
725490TYA.CSV	FORT DODGE (AWOS)	4171.02	2338.40	32463.40	595.71
725493TYA.CSV	KNOXVILLE	4733.20	2635.74	29497.28	799.61
725494TYA.CSV	RED OAK	4145.91	2551.22	29746.10	595.71
725495TYA.CSV	SHELDON	4224.56	2501.45	31706.06	595.71
725496TYA.CSV	STORM LAKE	4163.73	2321.38	32552.81	595.71
725497TYA.CSV	COUNCIL BLUFFS	4143.29	2576.68	29440.78	595.71

725500TYA.CSV	OMAHA EPPLEY AIRFIELD	4176.92	2628.17	29599.35	595.71
725510TYA.CSV	LINCOLN MUNICIPAL ARPT	4079.98	2509.85	29119.92	595.71
725515TYA.CSV	BEATRICE MUNICIPAL	3982.09	2404.39	28381.65	595.71
725520TYA.CSV	GRAND ISLAND CENTRAL NE REGIO	4091.24	2299.62	31599.33	595.71
725524TYA.CSV	ORD/SHARP FIELD	4028.87	2266.20	30718.37	595.71
725525TYA.CSV	HASTINGS MUNICIPAL	4035.20	2357.57	29903.50	595.71
725526TYA.CSV	KEARNEY MUNI (AWOS)	4100.22	2316.02	31472.76	595.71
725527TYA.CSV	TEKAMAH (ASOS)	4183.96	2505.78	31036.34	595.71
725530TYA.CSV	OMAHA WSFO	4124.93	2457.02	30474.43	595.71
725533TYA.CSV	FALLS CITY/BRENNER	4037.74	2464.17	28755.17	595.71
725540TYA.CSV	BELLEVUE OFFUTT AFB	4096.84	2472.53	29833.95	595.71
725555TYA.CSV	BROKEN BOW MUNI	4143.21	2287.47	32592.70	595.71
725556TYA.CSV	AINSWORTH MUNICIPAL	3930.30	2139.88	30269.02	595.71
725560TYA.CSV	NORFOLK KARL STEFAN MEM ARPT	4092.62	2257.35	32077.56	595.71
725564TYA.CSV	FREMONT MUNI ARPT	4134.83	2323.12	31989.43	595.71
725565TYA.CSV	COLUMBUS MUNI	4142.65	2377.59	31554.63	595.71
725566TYA.CSV	O`NEILL/BAKER FIELD	4172.70	2186.60	34125.10	595.71
725570TYA.CSV	SIOUX CITY SIOUX GATEWAY AP	4121.21	2351.05	31593.88	595.71
725610TYA.CSV	SIDNEY MUNICIPAL AP	4017.65	1983.17	33098.89	595.71
725620TYA.CSV	NORTH PLATTE REGIONAL AP	4034.11	2167.95	31976.77	595.71
725625TYA.CSV	MCCOOK MUNICIPAL	3993.73	2321.88	29536.54	595.71
725626TYA.CSV	IMPERIAL FAA AP	3937.80	2161.95	30223.12	595.71
725628TYA.CSV	BREWSTER FIELD ARPT	4062.09	2280.20	31155.56	595.71
725635TYA.CSV	ALLIANCE MUNICIPAL	4020.44	2042.61	33023.89	610.83
725636TYA.CSV	CHADRON MUNICIPAL AP	4009.93	2066.27	31946.46	610.83
725640TYA.CSV	CHEYENNE MUNICIPAL ARPT	4170.49	1886.85	36953.34	610.83
725645TYA.CSV	LARAMIE GENERAL BREES FIELD	3683.31	1878.45	38829.14	610.83
725650TYA.CSV	DENVER INTL AP	3964.01	2053.30	31363.61	610.83
725660TYA.CSV	SCOTTSBLUFF W B HEILIG FIELD	3969.63	2025.00	32358.92	610.83
725670TYA.CSV	VALENTINE MILLER FIELD	3958.64	2114.31	31203.51	595.71
725690TYA.CSV	CASPER NATRONA CO INTL AP	4193.59	1963.65	36504.11	306.55
725700TYA.CSV	CRAIG-MOFFAT	4368.42	1907.83	40259.95	610.83
725705TYA.CSV	VERNAL	3448.93	2008.55	33876.02	306.55
725715TYA.CSV	HAYDEN/YAMPA (AWOS)	4347.54	1888.59	40097.17	610.83
725717TYA.CSV	RIFLE/GARFIELD RGNL	4066.57	2073.73	32907.29	610.83
725720TYA.CSV	SALT LAKE CITY INT'L ARPT [ISIS]	3103.62	2031.53	27522.20	306.55
725724TYA.CSV	PROVO MUNI (AWOS)	3221.52	2006.25	29737.67	306.55
725744TYA.CSV	ROCK SPRINGS ARPT [GREEN RIVER - UO]	3732.24	1903.11	39586.67	306.55
725745TYA.CSV	RAWLINS MUNICIPAL AP	3633.23	1912.57	37734.62	610.83
725750TYA.CSV	OGDEN HINKLEY AIRPORT	3249.76	2041.53	30093.01	306.55
725755TYA.CSV	OGDEN HILL AFB	3355.15	2070.95	31832.32	306.55
725760TYA.CSV	LANDER HUNT FIELD	4253.64	1948.25	37771.19	610.83
725765TYA.CSV	RIVERTON MUNICIPL AP	4233.49	2010.10	36690.11	610.83

725775TYA.CSV	EVANSTON/BURNS FLD	3769.17	1874.35	40413.23	306.55
725776TYA.CSV	JACKSON HOLE	4498.33	1846.41	43283.57	306.55
725780TYA.CSV	POCATELLO REGIONAL AP	3446.96	1969.61	34068.32	306.55
725785TYA.CSV	IDAHO FALLS FANNING FIELD	3535.18	1914.74	35967.11	306.55
725786TYA.CSV	MALAD CITY	3385.83	2025.82	32604.92	306.55
725805TYA.CSV	LOVELOCK DERBY FIELD	3275.29	2088.77	30296.15	306.55
725810TYA.CSV	WENDOVER USAF AUXILIARY FIELD	3380.68	2121.22	31985.52	306.55
725825TYA.CSV	ELKO MUNICIPAL ARPT	3593.75	2035.82	36353.84	306.55
725830TYA.CSV	WINNEMUCCA MUNICIPAL ARPT	3422.34	2070.91	33066.95	306.55
725845TYA.CSV	BLUE CANYON AP	3023.37	1889.93	29278.18	237.62
725846TYA.CSV	TRUCKEE-TAHOE	3521.71	1911.75	38123.04	306.55
725847TYA.CSV	SOUTH LAKE TAHOE	3532.49	1850.03	38626.53	306.55
725865TYA.CSV	HAILEY/FRIEDMAN MEM	3608.87	2039.27	36599.31	306.55
725866TYA.CSV	JOSLIN FLD MAGIC VA [TWIN FALLS - UO]	3280.64	1950.10	31161.62	306.55
725867TYA.CSV	BURLEY MUNICIPAL ARPT	3272.11	1941.90	31056.99	306.55
725868TYA.CSV	SODA SPRINGS/TIGERT	3657.95	1917.92	38104.73	306.55
725895TYA.CSV	KLAMATH FALLS INTL AP [UO]	3310.71	1895.20	32010.84	306.55
725905TYA.CSV	UKIAH MUNICIPAL AP	2479.42	2001.17	18988.07	237.62
725910TYA.CSV	RED BLUFF MUNICIPAL ARPT	2478.54	2271.89	17804.13	237.62
725920TYA.CSV	REDDING MUNICIPAL ARPT	2429.72	2216.53	17161.17	237.62
725945TYA.CSV	ARCATA AIRPORT	2578.69	1852.07	21425.01	237.62
725946TYA.CSV	CRESCENT CITY FAA AI	2709.97	1861.90	21371.02	306.55
725955TYA.CSV	MONTAGUE SISKIYOU COUNTY AP	3057.43	1956.33	27099.81	306.55
725958TYA.CSV	ALTURAS	3360.82	1988.57	32390.40	306.55
725970TYA.CSV	MEDFORD ROGUE VALLEY INTL AP [ASHLAND - UO]	2830.60	1925.60	23194.28	306.55
725975TYA.CSV	SEXTON SUMMIT	3079.45	1846.15	28110.22	306.55
725976TYA.CSV	LAKEVIEW (AWOS)	3493.60	1932.57	35047.54	306.55
726050TYA.CSV	CONCORD MUNICIPAL ARPT	3298.31	2129.25	32684.39	251.58
726055TYA.CSV	PEASE INTL TRADEPOR	3186.35	2154.28	30540.42	251.58
726060TYA.CSV	PORTLAND INTL JETPORT	3308.09	2099.49	32994.34	251.58
726064TYA.CSV	SANFORD MUNI (AWOS)	3286.46	1952.11	33209.65	251.58
726073TYA.CSV	WATERVILLE (AWOS)	3406.40	2058.51	34892.13	251.58
726077TYA.CSV	BAR HARBOR (AWOS)	3296.34	1919.13	33541.38	251.58
726079TYA.CSV	ROCKLAND/KNOX(AWOS)	3225.66	1971.04	32033.24	251.58
726083TYA.CSV	NORTHERN AROOSTOOK	3631.41	1967.49	39443.09	251.58
726088TYA.CSV	BANGOR INTERNATIONAL AP	3310.00	2058.16	33207.60	251.58
726115TYA.CSV	SPRINGFIELD/HARTNES	3248.26	2106.27	31881.89	251.58
726116TYA.CSV	LEBANON MUNICIPAL	3324.67	2139.31	33108.04	251.58
726130TYA.CSV	MOUNT WASHINGTON	4204.94	1786.21	50624.76	251.58
726145TYA.CSV	MONTPELIER AP	3315.28	2058.93	33304.52	251.58
726155TYA.CSV	LACONIA MUNI (AWOS)	3252.47	2050.27	32154.01	251.58
726160TYA.CSV	BERLIN MUNICIPAL	3491.82	2020.62	36668.26	251.58

726165TYA.CSV	DILLANT HOPKINS	3273.28	2098.86	32312.41	251.58
726170TYA.CSV	BURLINGTON INTERNATIONAL AP	3282.57	2095.20	32556.30	251.58
726184TYA.CSV	AUBURN-LEWISTON	3311.36	2017.22	33358.81	251.58
726185TYA.CSV	AUGUSTA AIRPORT	3318.87	2145.15	32990.52	251.58
726196TYA.CSV	MILLINOCKET MUNICIPAL AP	3334.59	2041.21	33726.86	251.58
726223TYA.CSV	MASSENA AP	3080.90	2133.01	33891.51	121.07
726227TYA.CSV	WATERTOWN AP	2981.79	2160.95	32038.21	121.07
726228TYA.CSV	ADIRONDACK RGNL	3230.64	2007.94	36850.78	121.07
726350TYA.CSV	GRAND RAPIDS KENT COUNTY INT'	4077.49	2198.99	31042.99	630.04
726355TYA.CSV	BENTON HARBOR/ROSS	4120.36	2374.02	29804.86	559.86
726357TYA.CSV	KALAMAZOO BATTLE CR	4002.91	2247.78	29126.33	630.04
726360TYA.CSV	MUSKEGON COUNTY ARPT	4109.89	2212.90	31458.77	630.04
726370TYA.CSV	FLINT BISHOP INTL ARPT	4086.26	2185.67	31364.60	630.04
726375TYA.CSV	OAKLAND CO INTL	4014.15	2287.66	28880.78	630.04
726379TYA.CSV	SAGINAW TRI CITY INTL AP	4103.55	2192.67	31594.86	630.04
726380TYA.CSV	HOUGHTON LAKE ROSCOMMON CO AR	4203.81	2098.80	34460.84	630.04
726384TYA.CSV	CADILLAC WEXFORD CO AP	4148.91	2076.61	33557.32	630.04
726385TYA.CSV	MANISTEE (AWOS)	4171.44	2226.59	32286.75	630.04
726387TYA.CSV	TRAVERSE CITY CHERRY CAPITAL	4108.64	2061.86	33167.15	630.04
726390TYA.CSV	ALPENA COUNTY REGIONAL AP	4172.44	2042.66	34551.73	630.04
726395TYA.CSV	OSCODA WURTSMITH AFB	4066.49	2121.45	31573.25	630.04
726400TYA.CSV	MILWAUKEE MITCHELL INTL AP	3992.37	2213.62	32210.13	559.86
726404TYA.CSV	MINOCQUA/WOODRUFF	4681.62	2067.57	36601.37	805.75
726410TYA.CSV	MADISON DANE CO REGIONAL ARPT [ISIS]	4705.91	2312.90	33600.18	805.75
726415TYA.CSV	JANESVILLE/ROCK CO.	4354.60	2084.73	30368.45	805.75
726416TYA.CSV	LONE ROCK FAA AP	4478.00	2251.03	30285.61	805.75
726430TYA.CSV	LA CROSSE MUNICIPAL ARPT	4195.40	2306.69	33428.98	595.71
726435TYA.CSV	EAU CLAIRE COUNTY AP	4244.27	2173.76	35736.67	595.71
726440TYA.CSV	ROCHESTER INTERNATIONAL ARPT	4214.24	2163.05	35317.90	595.71
726450TYA.CSV	GREEN BAY AUSTIN STRAUBEL INT	4648.00	2223.65	33841.07	559.86
726455TYA.CSV	MANITOWAC MUNI AWOS	4440.36	2109.78	31553.83	805.75
726456TYA.CSV	WITTMAN RGNL	4613.41	2159.30	34180.93	805.75
726457TYA.CSV	APPLETON/OUTAGAMIE	3955.27	2200.89	31527.52	559.86
726458TYA.CSV	STURGEON BAY	4447.63	2060.28	32414.03	805.75
726463TYA.CSV	WAUSAU MUNICIPAL ARPT	4642.16	2174.36	34453.21	805.75
726464TYA.CSV	WATERTOWN	4042.36	2425.33	30895.38	559.86
726465TYA.CSV	MOSINEE/CENTRAL WI	4708.20	2086.05	36720.45	805.75
726467TYA.CSV	RICE LAKE MUNICIPAL	4351.22	2247.05	36720.15	595.71
726468TYA.CSV	PHILLIPS/PRICE CO.	4218.74	2102.80	35873.76	595.71
726480TYA.CSV	ESCANABA (AWOS)	4589.85	1980.98	36102.86	595.71
726487TYA.CSV	MENOMINEE (AWOS)	4480.48	2026.19	33498.33	805.75
726498TYA.CSV	FAIR FIELD	4146.25	2589.19	29343.50	799.61

726499TYA.CSV	ESTHERVILLE MUNI	4316.32	2259.95	36115.64	595.71
726500TYA.CSV	SPENCER	4238.02	2241.39	34885.82	595.71
726510TYA.CSV	SIOUX FALLS FOSS FIELD	4174.72	2232.03	33843.36	595.71
726515TYA.CSV	BROOKINGS (AWOS)	4130.44	2090.35	34480.97	595.71
726525TYA.CSV	CHAN GURNEY MUNI	4151.90	2289.32	32646.92	595.71
726540TYA.CSV	HURON REGIONAL ARPT	4191.86	2147.37	35059.37	595.71
726544TYA.CSV	ORR	4458.22	1984.21	41426.25	595.71
726545TYA.CSV	MITCHELL (AWOS)	4283.59	2332.05	34651.49	595.71
726546TYA.CSV	WATERTOWN MUNICIPAL AP	4263.08	2123.21	36605.51	595.71
726547TYA.CSV	GLENWOOD (ASOS)	4241.76	2189.42	35328.63	595.71
726550TYA.CSV	ST CLOUD REGIONAL ARPT	4278.86	2108.59	37085.48	595.71
726555TYA.CSV	BRAINERD/WIELAND	4206.92	2072.47	36146.35	595.71
726556TYA.CSV	REDWOOD FALLS MUNI	4211.18	2247.46	34339.03	595.71
726557TYA.CSV	ALEXANDRIA MUNICIPAL AP	4320.50	2186.57	36967.85	595.71
726558TYA.CSV	CLOQUET (AWOS)	4368.75	2139.77	38175.70	595.71
726559TYA.CSV	MARSHALL/RYAN(AWOS)	4181.67	2209.02	34032.90	595.71
726560TYA.CSV	FERGUS FALLS(AWOS)	4186.63	2206.84	34273.63	595.71
726563TYA.CSV	FARIBAULT MUNI AWOS	4171.07	2269.96	33236.77	595.71
726564TYA.CSV	RED WING	4238.60	2316.20	33939.40	595.71
726565TYA.CSV	MORRIS MUNI (AWOS)	4318.95	2179.70	36834.07	595.71
726566TYA.CSV	PIPESTONE (AWOS)	4391.81	2301.03	36887.53	595.71
726567TYA.CSV	NEW ULM MUNI (AWOS)	4207.04	2293.96	33609.38	595.71
726568TYA.CSV	OWATONNA (AWOS)	4187.35	2263.77	33546.56	595.71
726569TYA.CSV	HUTCHINSON (AWOS)	4321.37	2301.03	35591.82	595.71
726574TYA.CSV	MARSHFIELD MUNI	4514.55	2123.88	32784.69	805.75
726575TYA.CSV	MINNEAPOLIS/CRYSTAL	4230.81	2158.34	35652.00	595.71
726576TYA.CSV	WILLMAR	4183.23	2256.36	33559.37	595.71
726578TYA.CSV	LITTLE FALLS (AWOS)	4330.39	2116.35	37722.45	595.71
726579TYA.CSV	FLYING CLOUD	4253.76	2304.85	34424.50	595.71
726580TYA.CSV	MINNEAPOLIS-ST PAUL INT'L ARP	4159.44	2198.67	33929.61	595.71
726583TYA.CSV	LITCHFIELD MUNI	4075.07	2117.85	33150.91	595.71
726584TYA.CSV	ST PAUL DOWNTOWN AP	4198.77	2222.84	34368.71	595.71
726585TYA.CSV	MANKATO(AWOS)	4194.88	2237.44	33997.47	595.71
726586TYA.CSV	FAIRMONT MUNI(AWOS)	4188.69	2233.74	33914.89	595.71
726587TYA.CSV	WORTHINGTON (AWOS)	4208.12	2194.37	34686.24	595.71
726588TYA.CSV	WINONA MUNI (AWOS)	4174.05	2245.05	33539.40	595.71
726589TYA.CSV	ALBERT LEA (AWOS)	4197.48	2389.55	32402.38	595.71
726590TYA.CSV	ABERDEEN REGIONAL ARPT	4202.82	2215.95	34505.53	595.71
726603TYA.CSV	SOUTH ST PAUL MUNI	4289.17	2338.68	34698.06	595.71
726620TYA.CSV	RAPID CITY REGIONAL ARPT	4055.93	1998.02	33643.74	610.83
726625TYA.CSV	ELLSWORTH AFB	4122.84	2025.11	34545.01	610.83
726626TYA.CSV	ANTIGO\LANG(AWOS)	4883.89	2307.56	36649.04	805.75
726650TYA.CSV	GILLETTE/GILLETTE-C	4014.51	2006.74	32775.38	610.83

726660TYA.CSV	SHERIDAN COUNTY ARPT	3423.68	1934.91	33846.51	610.83
726665TYA.CSV	WORLAND MUNICIPAL	4112.87	1971.62	34931.09	610.83
726676TYA.CSV	GLENDIVE(AWOS)	3584.47	1928.40	36707.29	306.55
726685TYA.CSV	MOBRIDGE	4272.41	2179.83	36156.33	595.71
726686TYA.CSV	PIERRE MUNICIPAL AP	4039.31	2128.56	32488.13	595.71
726700TYA.CSV	CODY MUNI (AWOS)	3552.83	1920.24	36191.95	306.55
726770TYA.CSV	BILLINGS LOGAN INT'L ARPT	3371.92	1929.93	32939.76	306.55
726776TYA.CSV	LEWISTOWN MUNICIPAL ARPT	3513.95	1844.86	35976.16	306.55
726785TYA.CSV	BUTTE BERT MOONEY ARPT	3798.40	1870.30	40968.57	306.55
726797TYA.CSV	BOZEMAN GALLATIN FIELD	3609.35	1929.60	37224.74	306.55
726798TYA.CSV	LIVINGSTON MISSION FIELD	3476.58	1937.44	34776.29	306.55
726810TYA.CSV	BOISE AIR TERMINAL [UO]	3137.32	2002.09	28303.81	306.55
726813TYA.CSV	CALDWELL (AWOS)	3175.80	1943.16	29268.72	306.55
726815TYA.CSV	MOUNTAIN HOME AFB	3345.36	2112.16	31438.82	306.55
726830TYA.CSV	BURNS MUNICIPAL ARPT [UO]	3475.35	1914.39	34886.30	306.55
726835TYA.CSV	REDMOND ROBERTS FIELD	3312.04	1895.70	32039.91	306.55
726865TYA.CSV	SALMON/LEMHI (AWOS)	3508.63	1909.27	35453.35	306.55
726880TYA.CSV	PENDLETON E OR REGIONAL AP	2976.78	1907.88	25919.00	306.55
726884TYA.CSV	LA GRANDE MUNI AP	3185.48	1893.10	29719.77	306.55
726886TYA.CSV	BAKER MUNICIPAL AP	3379.82	1890.00	33279.03	306.55
726904TYA.CSV	ROSEBURG REGIONAL AP	2692.66	1966.76	20473.82	306.55
726917TYA.CSV	NORTH BEND MUNI AIRPORT	2669.18	1846.47	20718.65	306.55
726930TYA.CSV	EUGENE MAHLON SWEET ARPT [UO]	2811.11	1941.92	22752.84	306.55
726940TYA.CSV	SALEM MCNARY FIELD	2756.16	1922.60	21863.79	306.55
726945TYA.CSV	CORVALLIS MUNI	2773.31	1945.37	22011.23	306.55
726959TYA.CSV	AURORA STATE	2752.42	1976.90	21488.22	306.55
726980TYA.CSV	PORTLAND INTERNATIONAL AP	2747.58	1987.92	21348.64	306.55
726985TYA.CSV	PORTLAND/TROUTDALE	2774.33	1948.97	22049.01	306.55
726986TYA.CSV	PORTLAND/HILLSBORO	2822.47	1966.76	22818.50	306.55
726988TYA.CSV	THE DALLES MUNICIPAL ARPT	2814.87	1972.33	22642.85	306.55
727033TYA.CSV	HOULTON INTL ARPT	3498.88	2022.57	36796.66	251.58
727120TYA.CSV	CARIBOU MUNICIPAL ARPT	3604.66	1960.03	39004.48	251.58
727130TYA.CSV	PRESQUE ISLE MUNICIP	3494.51	1901.74	37186.81	251.58
727135TYA.CSV	WISCASSET	3166.14	2143.36	30226.43	251.58
727340TYA.CSV	SAULT STE MARIE SANDERSON FIE	4129.37	1974.10	37129.24	559.86
727344TYA.CSV	CHIPPEWA CO INTL	4115.47	1931.64	37225.29	559.86
727347TYA.CSV	PELLSTON EMMET COUNTY AP	4124.06	2155.82	32365.20	630.04
727415TYA.CSV	RHINELANDER ONEIDA	4728.50	2127.91	36591.68	805.75
727437TYA.CSV	IRON MOUNTAIN/FORD	4131.34	2147.34	35370.48	559.86
727440TYA.CSV	HANCOCK HOUGHTON CO AP	4653.61	2020.07	36933.72	805.75
727444TYA.CSV	TWO HARBORS	4292.14	2054.99	37729.03	595.71
727445TYA.CSV	IRONWOOD (AWOS)	4255.15	2021.82	37380.01	595.71
727450TYA.CSV	DULUTH INTERNATIONAL ARPT	4295.57	1965.37	38925.97	595.71

727452TYA.CSV	CROOKSTON MUNI FLD	4259.02	2056.88	37064.54	595.71
727453TYA.CSV	PARK RAPIDS MUNICIPAL AP	4269.29	2043.68	37529.24	595.71
727455TYA.CSV	HIBBING CHISHOLM-HIBBING AP	4387.80	2042.36	39730.87	595.71
727457TYA.CSV	DETROIT LAKES(AWOS)	4235.85	2105.54	36149.49	595.71
727458TYA.CSV	GRAND RAPIDS(AWOS)	4256.88	1976.83	37896.74	595.71
727459TYA.CSV	ELY MUNI	4315.66	2035.31	38370.37	595.71
727470TYA.CSV	INTERNATIONAL FALLS INTL AP	4422.55	2016.03	40676.86	595.71
727473TYA.CSV	CRANE LAKE (AWOS)	4373.29	1960.62	40149.50	595.71
727474TYA.CSV	EVELETH MUNI (AWOS)	4408.93	2051.28	39838.60	595.71
727475TYA.CSV	MORA MUNI (AWOS)	4262.68	2127.15	36413.72	595.71
727476TYA.CSV	BAUDETTE INTERNATIONAL AP	4163.04	1979.84	36327.99	595.71
727477TYA.CSV	ROSEAU MUNI (AWOS)	4366.52	2078.04	38794.18	595.71
727478TYA.CSV	HALLOCK	4367.59	2130.62	38352.22	595.71
727503TYA.CSV	CAMBRIDGE MUNI	4303.86	2165.82	36716.78	595.71
727504TYA.CSV	AITKIN NDB(AWOS)	4294.58	2084.88	37416.59	595.71
727505TYA.CSV	FOSSTON(AWOS)	4400.82	2054.42	39679.92	595.71
727507TYA.CSV	BENSON MUNI	4281.85	2225.61	35670.83	595.71
727530TYA.CSV	FARGO HECTOR INTERNATIONAL AP	4314.09	2094.31	37876.80	595.71
727533TYA.CSV	WHEATON NDB (AWOS)	4274.36	2157.12	36291.34	595.71
727535TYA.CSV	JAMESTOWN MUNICIPAL ARPT	4406.46	2159.87	38787.96	595.71
727550TYA.CSV	BEMIDJI MUNICIPAL	4275.13	2004.02	37918.11	595.71
727555TYA.CSV	THIEF RIVER(AWOS)	4332.36	2065.71	38295.55	595.71
727556TYA.CSV	SILVER BAY	4387.34	1918.42	40886.22	595.71
727566TYA.CSV	AUSTIN MUNI	4240.52	2292.98	34226.54	595.71
727573TYA.CSV	DEVILS LAKE(AWOS)	4234.00	1930.99	38016.48	595.71
727575TYA.CSV	GRAND FORKS AF	4238.93	2090.03	36519.22	595.71
727576TYA.CSV	GRAND FORKS INTERNATIONAL AP	4378.86	2128.93	38660.30	595.71
727640TYA.CSV	BISMARCK MUNICIPAL ARPT [ISIS]	4144.77	2002.06	35803.38	595.71
727645TYA.CSV	DICKINSON MUNICIPAL AP	4268.30	2005.77	37936.42	595.71
727670TYA.CSV	WILLISTON SLOULIN INTL AP	3562.03	1969.26	36173.09	306.55
727675TYA.CSV	MINOT AFB	4163.00	1977.93	36357.20	595.71
727676TYA.CSV	MINOT FAA AP	4171.11	1928.19	37041.49	595.71
727680TYA.CSV	GLASGOW INTL ARPT	3517.00	1933.32	35545.66	595.71
727686TYA.CSV	WOLF POINT INTL [FORT PECK - SURFRAD]	4230.86	1960.63	37736.16	306.55
727687TYA.CSV	SIDNEY-RICHLAND	3735.88	1978.90	39166.44	306.55
727720TYA.CSV	HELENA REGIONAL AIRPORT	3501.58	1880.78	35559.60	306.55
727730TYA.CSV	MISSOULA INTERNATIONAL AP	3380.51	1890.89	33312.18	306.55
727750TYA.CSV	GREAT FALLS INTL ARPT	3545.94	1903.67	36231.58	306.55
727770TYA.CSV	HAVRE CITY-COUNTY AP	3542.38	1932.45	36014.70	306.55
727790TYA.CSV	KALISPELL GLACIER PK INT'L AR	3438.23	1869.31	34464.75	306.55
727796TYA.CSV	CUT BANK MUNI AP	3587.65	1841.48	37316.45	306.55
727810TYA.CSV	YAKIMA AIR TERMINAL	3095.45	1892.15	28149.17	306.55

727815TYA.CSV	STAMPEDE PASS	3562.93	1804.43	37067.02	306.55
727825TYA.CSV	WENATCHEE/PANGBORN	3053.18	1912.47	27273.61	306.55
727826TYA.CSV	EPHRATA AP FCWOS	3024.21	1933.37	26628.09	306.55
727827TYA.CSV	MOSES LAKE GRANT COUNTY AP	2991.37	1925.93	26078.98	306.55
727830TYA.CSV	LEWISTON NEZ PERCE CNTY AP	3009.86	1962.80	26209.27	306.55
727834TYA.CSV	COEUR D`ALENE(AWOS)	3254.67	1893.20	30959.42	306.55
727840TYA.CSV	HANFORD	3109.04	2020.18	27685.93	306.55
727845TYA.CSV	PASCO	2890.64	1992.46	23886.46	306.55
727846TYA.CSV	WALLA WALLA CITY COUNTY AP	2885.79	1940.52	24097.78	306.55
727850TYA.CSV	SPOKANE INTERNATIONAL AP [CHENEY - UO]	3232.86	1885.00	30671.06	306.55
727855TYA.CSV	FAIRCHILD AFB	3375.28	1925.91	33013.04	306.55
727856TYA.CSV	FELTS FLD	3125.96	1914.03	28574.65	306.55
727857TYA.CSV	PULLMAN/MOSCOW RGNL	3205.03	1923.13	29945.66	306.55
727885TYA.CSV	WILLIAM R FAIRCHILD	2913.52	1831.60	25208.76	306.55
727910TYA.CSV	ASTORIA REGIONAL AIRPORT	2775.25	1915.76	22249.00	306.55
727920TYA.CSV	OLYMPIA AIRPORT	2856.19	1901.36	23785.71	306.55
727923TYA.CSV	HOQUIAM AP	2798.27	1909.93	22696.83	306.55
727924TYA.CSV	KELSO WB AP	2804.31	1919.10	22718.17	306.55
727926TYA.CSV	TOLEDO-WINLOCK MEM	2981.59	1903.91	26033.87	306.55
727928TYA.CSV	BREMERTON NATIONAL	2912.03	1865.38	24957.60	306.55
727930TYA.CSV	SEATTLE SEATTLE-TACOMA INTL A	2769.57	1869.09	22407.02	306.55
727934TYA.CSV	RENTON MUNI	2735.96	1924.12	21491.01	306.55
727935TYA.CSV	SEATTLE BOEING FIELD [ISIS]	2707.29	1900.86	21104.29	306.55
727937TYA.CSV	SNOHOMISH CO	2821.09	1884.78	23246.44	306.55
727938TYA.CSV	TACOMA NARROWS	2766.27	1880.58	22282.29	306.55
727970TYA.CSV	QUILLAYUTE STATE AIRPORT	2848.48	1857.40	23894.85	306.55
727976TYA.CSV	BELLINGHAM INTL AP	2950.73	1908.82	25447.14	306.55
742060TYA.CSV	TACOMA MCCHORD AFB	2956.49	1876.76	25736.61	306.55
742070TYA.CSV	GRAY AAF	2927.10	1883.56	25162.20	306.55
742300TYA.CSV	MILES CITY MUNICIPAL ARPT	3464.35	1954.56	34478.64	306.55
743700TYA.CSV	FORT DRUM/WHEELER-S	2984.13	2114.00	32182.95	121.07
743920TYA.CSV	NAVAL AIR STATION	3298.83	2139.32	32645.13	251.58
743945TYA.CSV	MANCHESTER AIRPORT	3138.79	2193.27	29502.34	251.58
744655TYA.CSV	AURORA MUNICIPAL	3993.90	2349.77	30820.71	559.86
744860TYA.CSV	NEW YORK J F KENNEDY INT'L AR	3082.39	2481.79	25641.52	285.06
744864TYA.CSV	REPUBLIC	3769.41	2421.01	25678.90	568.95
744865TYA.CSV	WESTHAMPTON GABRESKI AP	3786.17	2327.84	26927.26	568.95
744904TYA.CSV	LAWRENCE MUNI	3090.13	2212.12	28524.47	251.58
744910TYA.CSV	CHICOPEE FALLS WESTO	3159.34	2232.90	29697.04	251.58
744915TYA.CSV	WESTFIELD BARNES MUNI AP	3202.72	2236.74	30468.43	251.58
745090TYA.CSV	MOUNTAIN VIEW MOFFETT FLD NAS	2382.98	2053.18	17027.17	237.62
745160TYA.CSV	TRAVIS FIELD AFB	2420.66	2085.83	17562.90	237.62

745700TYA.CSV	DAYTON WRIGHT PATTERSON AFB	3820.91	2312.45	28111.93	559.86
745940TYA.CSV	ANDREWS AFB	3244.64	2519.82	25664.29	343.34
745966TYA.CSV	CAPE MAY CO	3124.70	2455.13	23857.07	343.34
745980TYA.CSV	LANGLEY AFB	3278.85	2753.58	24163.48	356.47
745985TYA.CSV	MARTINSVILLE	3833.40	2551.31	25821.52	559.86
746120TYA.CSV	CHINA LAKE NAF	2816.65	2601.64	22480.89	237.62
746710TYA.CSV	FORT CAMPBELL AAF	3778.59	2858.63	25215.25	495.05
746716TYA.CSV	BOWLING GREEN WARREN CO AP	3719.77	2813.91	24559.14	495.05
746930TYA.CSV	FORT BRAGG SIMMONS AAF	3231.36	2950.58	22034.79	356.47
746943TYA.CSV	ELIZABETH CITY COAST GUARD AI [NREL]	3166.31	3070.67	20079.80	356.47
747020TYA.CSV	LEMOORE REEVES NAS	2430.01	2242.57	17054.80	237.62
747185TYA.CSV	IMPERIAL	3091.51	2861.32	13030.49	489.61
747187TYA.CSV	PALM SPRINGS THERMAL AP	2367.55	2835.37	13365.28	489.61
747188TYA.CSV	BLYTHE RIVERSIDE CO ARPT	3288.91	3075.99	14689.78	237.62
747320TYA.CSV	HOLLOMAN AFB	3384.00	2334.01	22988.28	489.61
747540TYA.CSV	ENGLAND AFB	3907.74	3442.05	18251.99	559.25
747685TYA.CSV	GULFPORT BILOXI INT	3854.95	3801.02	18305.49	492.83
747686TYA.CSV	KEESLER AFB	3849.39	3707.28	19041.39	492.83
747750TYA.CSV	TYNDALL AFB	3776.58	3554.14	19096.36	492.83
747770TYA.CSV	VALPARAISO HURLBURT	3850.04	3677.79	19314.61	492.83
747804TYA.CSV	HUNTER AAF	3755.77	3400.90	20084.58	492.83
747810TYA.CSV	MOODY AFB/VALDOSTA	3649.71	3266.07	19369.68	492.83
747880TYA.CSV	MACDILL AFB	3706.49	4048.07	16860.09	446.42
747900TYA.CSV	SUMTER SHAW AFB	3202.50	2903.45	21817.75	356.47
747910TYA.CSV	MYRTLE BEACH AFB	3197.05	3183.07	19893.19	356.47
747915TYA.CSV	NORTH MYRTLE BEACH GRAND STRA	3190.47	3190.74	19749.43	356.47
747946TYA.CSV	NASA SHUTTLE FCLTY	3653.03	3995.82	16320.25	446.42
911650TYA.CSV	LIHUE AIRPORT	4199.25	4449.56	15289.07	535.12
911760TYA.CSV	KANEOHE BAY MCAS	5184.37	4229.71	14315.26	804.58
911780TYA.CSV	BARBERS POINT NAS	4937.45	3962.61	13736.97	804.58
911820TYA.CSV	HONOLULU INTL ARPT	5047.11	4082.15	13979.26	804.58
911860TYA.CSV	MOLOKAI (AMOS)	3787.50	3833.14	13812.33	535.12
911900TYA.CSV	KAHULUI AIRPORT	3968.61	4102.37	14478.11	535.12
911904TYA.CSV	KAPALUA	3688.86	3743.46	12897.80	535.12
911905TYA.CSV	LANAI	3655.00	3593.24	13754.17	535.12
911975TYA.CSV	KONA INTL AT KEAHOL	4000.45	4212.09	13987.14	535.12
912850TYA.CSV	HILO INTERNATIONAL AP	4055.29	4200.22	15108.14	535.12

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