Comparison of the Lifetime Costs and Water Footprint of Sod and Artificial Turf: A Life Cycle Analysis

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June 2, 2016

Executive Summary

Motivated by the California drought conditions and changing landscapes, our life cycle analysis attempts to quantify the materials, processes, and maintenance that goes into producing and maintaining a m^2 of sod and a m^2 of turf. Each of theses are highly comparable in their usage and purpose either as a residential lawn or as matting for an athletic field. The two most important aspects of deciding whether to purchase sod or turf are that of cost and overall water usage, which are the major impact categories of our study. Our team searched through the literature, data files, and other inventories to quantify the materials used in each production, their costs (based on the context of industrial standards), as well as the amount of water it takes to produce these resources. Once all of our data was compiled and verified, we then added up the total production costs and water uses as well as the maintenance costs for the assumed lifetime of each product (a m^2 of sod and a m^2 of turf). The maintenance use costs were discounted to account for market changes over time. We also performed a sensitivity analysis to determine the most variable aspects of our results, which are water maintenance, energy, and the material used in artificial turf binding (the backing material for the carpet-like final product).

Our study determined that overall, based on the materials, processes, and years of use we considered, it costs more to produce a m^2 of turf in comparison to sod. However, when factoring in the maintenance for the lifecycle of each product, in the long run, a m^2 of sod requires more water to be maintained. Based solely on the computations of this report from a water-use perspective, it is better to purchase and install an artificial turf lawn over sod. Although, if you live in an area with higher rainfall, where water use is not an issue, the resources used in the production of artificial turf carry a higher impact than that of sod, in which case the latter would be a more economical and environmentally motivated choice. It is important to note that other lurking variables were not considered in this study such as the environmental implications of turf which causes chemical leaching into soils, suffocation of terrestrial habitats, and may cause harm to athletes (in the form of rug-burn or burns).

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Goal and Scope of Definition

California has been in a state of extreme drought for the past four years. Despite being prone to sporadic droughts throughout the state's history, traditional “lawn” landscapes are still present throughout California housing developments. In recent years, there has been a movement towards artificial turf replacement, especially for sports facilities and football fields (Anderson et al. 2008). These replacement projects have been motivated by the idea that artificial turf uses less water in the long-run. Through our research, we took inventory on all relevant materials and resources that go into making traditional lawn (in the form of laying sod rolls) as well as artificial turf replacements. Our life cycle analysis of these two comparable products attempted to catalogue all relevant materials, utility uses, and production mechanisms that go into producing 1 m^2 of sod and 1 m^2 of turf, which were then scaled for the size of an average lawn, reported to be one fifth of an acre (~800 m^2) as well as for a football field (~5350 m^2) (Chapman, 2016). The lifespan of these products were also considered, estimated to be around 10-15 years for both products assuming proper care and upkeep (Turf Evolution, 2016). (Note that sod can either die off quickly or last for years once rooted, if watered correctly. The lifetime estimation for sod took into account both the probable time an individual may own the same home and care for their lawn and it also normalized our long-term comparisons.) The context of our study is rooted in the base production of these products as well as a year of use and maintenance. To avoid contextual biases, we have evaluated the end lifecycle for a lawn and recreation field after first normalizing the data to a single m^2 of product. The resources used to transport and install these products sod are negligible and have therefore been excluded from our study. To account for the changes in value investment over the lifetime of these products, we have also discounted the costs for use and maintenance for 15 years.

Literature Review

As artificial turf has gained prominence over the years, a variety of life cycle assessments (both public and private) have been conducted in order to determine possible health implications as well as determine overall resource use. An independent life cycle assessment prepared for Brock USA by the mutual efforts of the Rocky Mountain Institute and the Athena Institute in 2007 is one of the most referenced materials on this matter (Athena Institute). This study was conducted “to provide independent data to decision makers such as architects, school districts, and park departments” in order to properly weigh the environmental implications of such synthetic products. The study parameters used an estimated 20 year lifespan, but also implied that the Brock USA product may last up to 50 years. This finding is likely biased but was still considered by our team. In order to account for other studies, we took the median life-span of turf to be 15 years (between 10-15 was the most common response, followed by 20). This study identified polypropylene resin, used as a binder in artificial turf as well as the main supply of artificial fibers, as a major contributor to overall cost in this product's lifecycle. This study also assumed that “all materials are landfilled at the end of their life cycle” (Athena Institute). More follow up studies were recommended and encouraged, however, this was one of the most comprehensive life cycle assessments we came across in our research.

Lawns and water use demands across the state of California are fundamental to our study. The paper entitled “Lawns and Water Demands in California” issued by the Public Policy Institute of California was used to quantify the actual water needs of existing California lawn owners and predict future needs. This report used residential housing data to access outdoor water needs of single-family homes and landscaping across California, including coastal and inland areas from San Francisco to the Inland Empire (Hanak, Davis, 2006). This report relates water use and needs to the growing population in California, and its associated growth in water demands. In 2000, California city suburbs used roughly 8.9 million acre-feet of water, which is about 232 gallons per person per day (Hanak, Davis, 2006). This study estimates that while overall water use will increase by 3.0 maf, per capita use will decrease to 221 gallons per capita daily. This study computes the average yard size, average annual water requirements, and percent increases for small single family lots, large single family lots, and multi-family lots in all major regions of California (Hanak, Davis, 2006). By far the most relevant aspect of this study was the comparison of the effects of climate and land use on outdoor water needs of turf grass in coastal, inter-coastal, central, and desert California landscapes. Another important topic covered in this paper was water pricing and rate structures: flat, declining block, uniform, and increasing block and how they may or may not vary with the amount of water used. This study concludes that education, outreach, and sensitive water pricing in addition to lawn community planning all hold a role in conserving water resources in California.

A final life cycle analysis conducted by the Government of Western Australia’s Department of Sport and Recreation informed our own analysis. “Natural grass v synthetic turf: Study report” goes beyond the life cycle cost to evaluate health impacts, social impacts, environmental impacts, sport requirements, local factors, and both demand and capacity. These considerations shape the report as a decision making tool. The report delves into the details of the components and manufacturing processes for creating artificial turf. It also describes details regarding artificial turf maintenance and varieties, which aided in the development of our flow diagrams. When the Department of Sport and Recreation presented the 25-year life cycle costs, natural grass was cheaper than either sand-filled or non sand-filled artificial turf--$656,611 versus $791,625 and $784,125, respectively (2011). The study does not have a conclusion. It simply lists costs and benefits associated with each choice, regarding all aforementioned factors.

Methods

I. Functional Unit

Our functional unit was 1 meter squared of land. Since both artificial turf and sod grass are produced and sold in terms of area, our team decided it made most sense to use area as our functional unit in our analysis. Originally, we thought about making our functional unit the area of an average Southern California lawn, but due to the immense variability in lawn and yard sizes we decided upon 1 square meter. In our analysis we looked at the cost (in U.S. dollars) and water use (in gallons) required for the production and use of 1 meter squared of artificial turf and sod. These two impact categories are the major factors that people consider when deciding between installing an artificial turf or a sod grass lawn.

Our team initially considered assessing energy consumption and carbon sequestration as additional impact categories, but due to time constraints and difficulty finding data, we decided to stick to the major factors: monetary cost and water use.

II. System Boundary

For our analysis, we researched the production and use processes for artificial turf and sod and created unit flow diagrams to show the materials and resources required for each. These flow diagrams can be seen in Figure 1 and Figure 2 below. To determine our system boundary, we assessed the major contributors and decided to take into account the inputs up to stage 2 since we deemed the inputs in further stages to be negligible. Additionally, we omitted installation and transportation on our flow diagrams and in our calculations since their inputs are relatively insignificant and the costs and inputs would be similar for the artificial turf and sod. For all of our major input processes there were no significant alternate products yielded so we did not have to deal with disaggregation or allocation.

III. Flow Diagrams

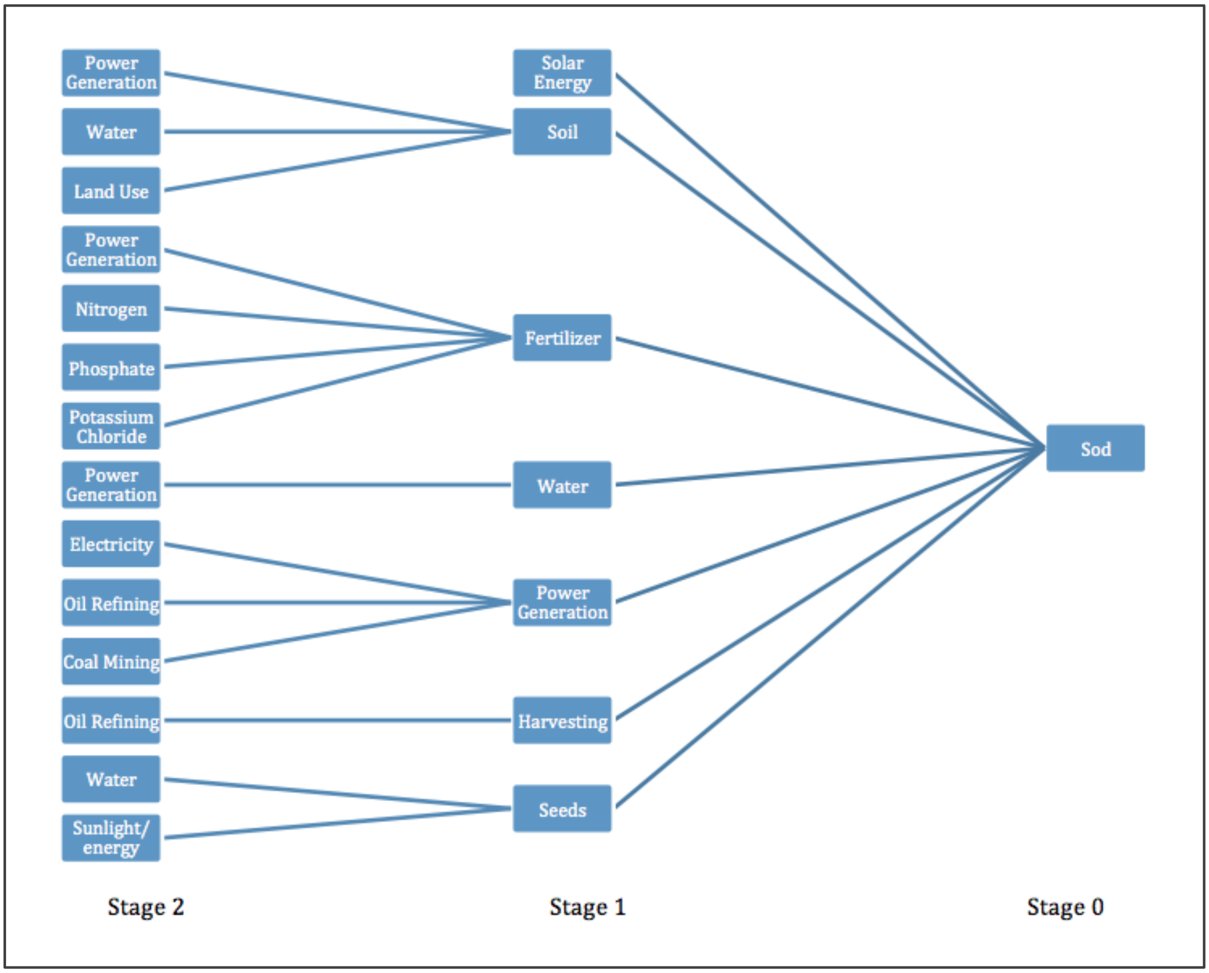

Figure 1: Sod Flow Diagram

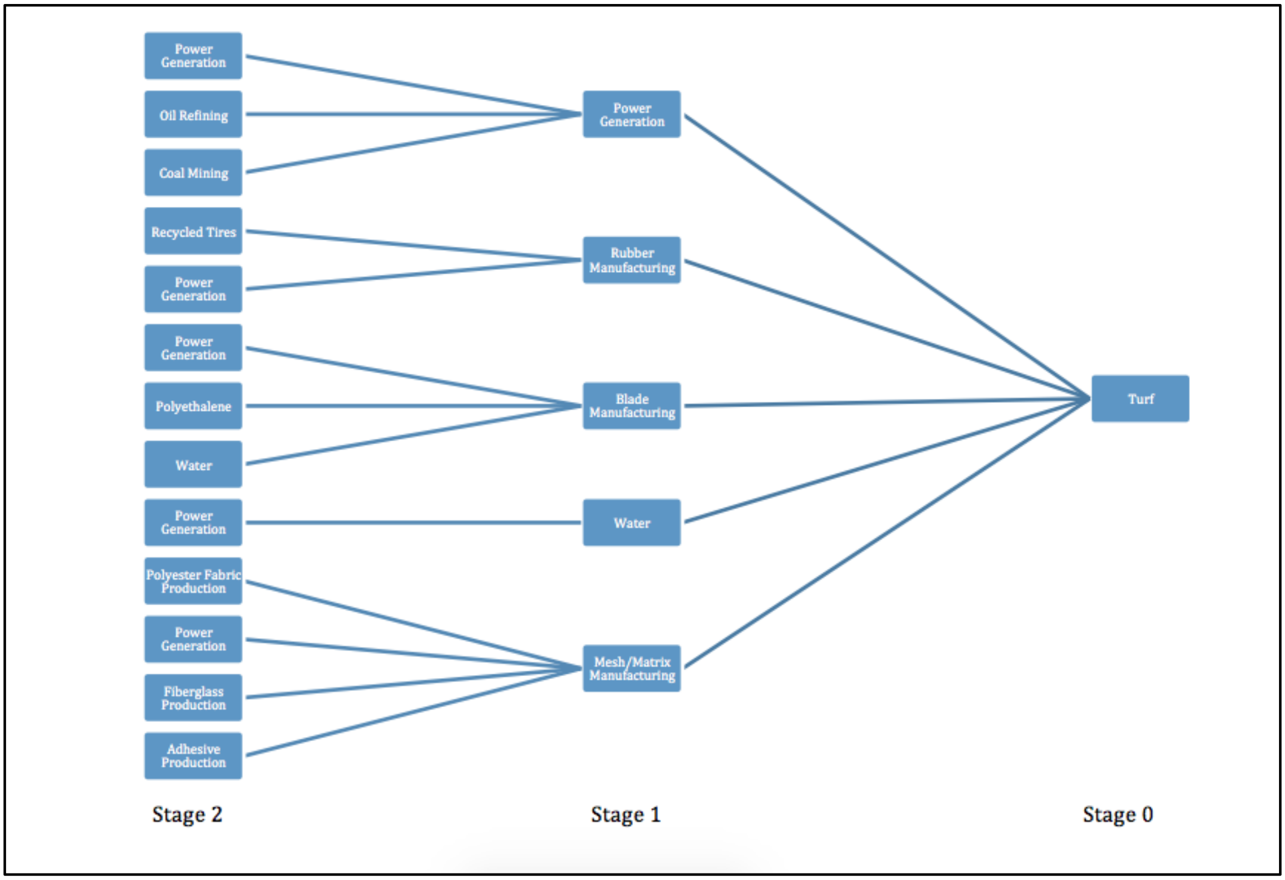

Figure 2: Artificial Turf Flow Diagram

IV. Method

In our analysis we used a combination of process LCA and EIOLCA. For the process LCA, we looked at specific unit processes by taking data, prices, and statistics from specific companies or papers. In addition to this, we used EIOLCA for a few processes to get data about the economy-wide impacts and costs.

Life Cycle Inventory

I. Summary of Data Sources

We collected data from a large number of sources including EIOLCA, EIA, LADWP, and a number of other manufacturers, sales merchants, and primary literature articles. The raw data used in our analysis and their respective source are summarized in Table 1 below.

Table 1: Summary of raw data and data sources

Data Type	Value	Source
Cost of Turf	$8.88/ft^2 of turf	Simon, 2010
Cost of Sod	$4.24/ft^2 of turf	Simon, 2010
Water Rates	$6.16/HCF	LADWP 2015 Tier 2 Rates
Electricity Rates	$0.15/kWh	EIA, 2016
Turf Production Energy Use	$4.31 TJ per $1 million of turf	EIOLCA 2002 Model - Rug and Carpet Mill Sector
Blade Weight	40 to 100 oz per yd^2 of turf	Synthetic Turf Council, Inc., 2013
Blade Water Use	18 kg of water per 1 kg polyethylene	CPM, 2008
Blade Costs	$82/lb	Naylor, 2014
Total Turf Production Water Use	1.79 kGal per $100 of turf	EIOLCA 2002 Model - Rug and Carpet Mill Sector
Stage 1 Turf Production Water Use	0.013 kGal per $100 of turf	EIOLCA 2002 Model - Rug and Carpet Mill Sector
Cost of polypropylene adhesive	$4.40/m^2 of turf	Homer, 2016
Cost of fiberglass	$0.50/m^2 of turf	AeroMarine Products, 2010
Cost of polyester yarn	$29.53/m^2 of turf	Uline
Water of polypropylene adhesive	0.0001592 Gal/m^2 of turf	Cherrett et al., 2005
Water of fiberglass	0.0001056 Gal/m^2 of turf	Maimoun, 2015
Water for polyester fabric	0.0000001 Gal/m^2 of turf	Cherrett et al., 2005
Harvesting Rates	7000 ft^2/hr	Bennett, 2016
Harvesting Gasoline Use	5 Gal/hr	Bennett, 2016
Cost of Gasoline	$3/Gal	Assumption
Sod Production Water Use	407.09 Gal/m^2 of turf	Saratoga Sod Farm, 2015 and Lavery's Sod Farm, 2013
Energy used in water supply	18.6 TJ per $1 Million of Water	EIOLCA 2002 Model - Water, Sewage and Other Systems Sector
Sod Prodution Initial Fertilizer Use	0.179 lb/yr for first 2 months	Duvauchelle et al. and University of Tennessee, 2000
Sod Prodution Regular Fertilizer Use	0.168 lb/yr for remaining 12 months	Duvauchelle et al. and University of Tennessee, 2000
Fertilizer used in Sod Upkeep	0.235 lb/yr	Duvauchelle et al. and University of Tennessee, 2000
Fertilizer Costs	$3.33/lb of fertilizer	The Scotts Company LLC., 2016
Sod Watering Recommendations	1.25 inches/wk	Walheim et al., 1016
Cost of Soil	$10/yd^3	CostHelper, 2016
Soil Moisture Content	10%	Brouwer et al., 1985
Weight of Seeds	1 lb per 150 ft^2 of sod	Do it Yourself or Not, 2016
Cost of Seeds	$49.98 per 20 lb bag	Lowe's, 2016
Seed Yield	500 lb of seeds produced per acre of sod	Sumner, 1949

II. EIOLCA Discussion

The online EIOLCA tool was critical to the success of this project. It is a great resource for obtaining a general understanding of certain lifecycle costs, but it is also highly limited by the resolution of the data. For the US 2002 producer data, there are only 428 sectors. That may sound like a fair number, but compared to the unfathomable number of products created in the US, it just barely scratches the surface. We used only “Water Withdrawals” and “Energy” outputs. All values were generated as output per million dollars of economic activity, divided by that one million, then multiplied by the price to produce 1m^2 of artificial turf or natural grass.

Table 2: Summary of the components that use data from EIOLCA outputs. Organized by product (artificial turf or natural grass) and impact category (cost or water).

Artificial Turf	
Cost	**Water**
Energy	Energy
Water	Water
Natural Grass	
Cost	**Water**
Energy	Energy
Harvesting	Harvesting
Fertilizer	Fertilizer

For turf, we used EIOLCA for estimates of both impact categories (cost and water) for the following inputs: energy and water. First, for energy, we looked at the power generation and supply category under the “Carpet and Rug Mills” sector. We assumed that the production process roughly mimicked that of turf, even though there are likely some differences. We then took this value for energy production per million dollars of economic output, divided by one million, multiplied by the cost to produce one square meter of artificial turf, and multiplied by the state’s average price per kWh, according to the US Energy Information Administration (Simon, 2010; EIA, 2016). This yielded cost of energy per square meter used to assemble the turf after all the components had been already manufactured. To get water used to assemble a square meter of turf, we took the EIOLCA “Water Withdrawal” value for “Carpet and Rug Mills” under the subcategory “Power generation and supply.” We again divided by one million dollars of economic activity and multiplied by the cost to produce one square meter of artificial turf. Finally, we converted kilogallons to gallons. Second, a very similar procedure was used for both impact categories for water. The only difference was a small modification to improve the accuracy of the EIOLCA. We took the “Water Withdrawal” total value from “Carpet and Rug Mill sector”. We noticed that the largest component of this number was cotton farming, which is not at all a part of artificial turf production. Thus, we subtracted this value from the total. We then multiplied by LADWP’s Tier 2 water rates to get the cost of water.

For natural grass, we used EIOLCA estimates for estimates of both impact categories (cost and water) for the following inputs: energy, harvesting, and fertilizer. Again, first, for the cost impact category, EIOLCA “Energy” output (in terajoules) was gathered from the “Power and generation" sector. EIA state average electricity price per kilowatt-hour was used to convert to cost. Second, both water and cost of harvesting (the act of scraping the sod off of the ground) were calculated in an analogous way. The output was "Water Withdrawals," and we multiplied by LADWP's Tier 2 water rates. Finally, we used the "Water Withdrawals" output for the "Fertilizer manufacturing" sector to get estimates of cost and water associated with creating fertilizer.

Base Calculation Results

To truly begin our analysis of artificial turf versus natural grass sod, we had to first develop some sort of base calculations. These calculations were broken up into two sections: production and upkeep. This mirrors the flow diagrams shown earlier, where the production stage represents all of the water and costs that go into the manufacturing of these products, and the upkeep stage represents all of the water and costs that go along with utilizing and maintaining your lawn.

1) Cost Analysis

With the exception of unit conversions, our values for the production stage were fairly self-explanatory considering that these were all initial, one-time costs. For the upkeep stage, however, we needed to normalize our values by some sort of time frame. We did this by performing our analysis for the aforementioned average lifespan of 15 years for both the turf and the sod. Once we determined values for the cost of upkeep per year, we then calculated a present value for these costs based on a discount rate of 5% compounded annually. Our final step was to simply sum up the present value for the product upkeep with the initial production costs in order to get a total discounted lifecycle cost for each product. A tabulated summary of our findings is shown in Tables 3 and 4 below.

Table 3: Base Calculation for Artificial Turf Lifecycle Cost

Turf	
Turf Production	**Base Calc ($/m^2)**
Energy	17.17
Rubber Manufacturing	-
Blade Manufacturing	4.27
Water	14.08
Backing Production	34.43
Total	*69.95*
Turf Upkeep	**Base Calc ($/m^2)**
Water	7.65
Total	*7.65*
Discounted PV for 15 Year Lifespan	*5.34*
Total Turf Life Cycle Cost = $75.29/m^2	

Table 4: Base Calculation for Natural Sod Lifecycle Cost

Sod	
Sod Production	**Base Calc ($/m^2)**
Sunlight	0
Harvesting	0.024
Energy	2.6
Seeds	0.18
Fertilizer	1.16
Water	3.35
Soil	0.33
Total	*7.64*
Sod Upkeep	**Base Calc ($/m^2/yr)**
Water	54
Fertilizer	12.15
Total	*66.15*
Discounted PV for 15 Year Lifespan	*45.77*
Total Sod Life Cylce Cost = $53.41/m^2	

2) Water Analysis

Similar to the cost analysis, the values obtained for water use during the turf production stage all represent initial, one-time costs. However, this analysis required a little more bookkeeping, as we had to keep straight which values were stage one inputs and which were stage two inputs so that we could avoid any double counting. The most obvious example of this is understanding the difference between the water that goes directly into watering the artificial turf or sod versus the water that goes into the energy that then goes into manufacturing the turf or sod. Since the units of this analysis consist of volumes (gallons) of water, there was no need for us to do any discounting during the upkeep stage. A tabulated summary of our findings is shown in Tables 5 and 6 below.

Table 5: Base Calculation for Artificial Turf Water Use

Turf	
Turf Production	**Base Calc (Gal/m^2)**
Energy	965.39
Rubber Manufacturing	-
Blade Manufacturing	11.27
Water	12.43
Backing Production	0.00026
Total	*989.09*
Turf Upkeep	**Base Calc (Gal/m^2)**
Water	937.2
Total	*937.2*
Total Turf Water Use = 1926 Gal/m^2	

Table 6: Base Calculation for Natural Grass Sod Water Use

Sod	
Sod Production	**Base Calc (Gal/m^2)**
Sunlight	0
Harvesting	0
Energy	914.13
Seeds	44
Fertilizer	0
Water	407.09
Soil	0.67
Total	*1365.89*
Sod Upkeep	**Base Calc (Gal/m^2)**
Water	6560.25
Fertilizer	-
Total	*6560.25*
Total Sod Water Use = 7926 Gal/m^2	

Impact Analysis

1) Water

The first impact category we chose to evaluate in our life cycle assessment was water. This is a highly relevant factor in the debate over artificial turf versus natural lawns, as water conservation is often given as the main justification for replacing a natural lawn with turf. It should be no surprise, then, that our lifecycle water consumption for artificial turf (1926.26 gal/m^2) was much lower than that of natural grass (7926.08 gal/m^2). Turf requires roughly 24.3% of the water that natural grass does.

For artificial turf, by far the two highest contributors to this water consumption were water used to create energy used in manufacturing artificial turf (50.12% of life cycle water consumption), and water used to clean the turf (48.65% of life cycle water consumption). The remaining 1.23% came from backing production, water used directly in production (stage one), and blade manufacturing. For natural grass, the largest component is by far the water used to irrigate the grass once it is installed. This represents 82.77% of the total water input. If you add in the water used to produce the sod, which is essentially just watering the lawn before it's rolled up and delivered to a home, then that figure rises to 87.90% of all water consumed. The next largest category is the water used in generating energy for sod production.

2) Costs

Our second impact category was cost. Cost is an indicator of the value and difficulty of creating something. It is also always a key predictor of decisions. In our case, the life cycle cost of one square meter of natural grass ($53.41) was much lower than that of artificial turf ($75.29). Artificial turf has a life cycle cost 40.96% greater than that of natural grass.

For artificial turf, the most expensive components are the backing production (45.73% of life cycle cost), followed by energy for production (18.71% of life cycle cost) and water for production (22.80% of life cycle cost). For natural grass, the 85.70% of the life cycle cost comes from the discounted price of supplying fertilizer and water for 15 years. That is, only 14.30% of the life cycle cost comes from the upfront cost. For the less wealthy sectors of the population that have lawns, the drastically lower upfront cost will push consumers toward natural grass lawns. Although the lifecycle and upfront costs are quantitatively differently, they are qualitatively similar; poor consumers will favor natural grass.

3) A Note on Energy

Note, we decided not to add energy as an impact category. In comparison to water and cost this aspect is not quite as significant. It would be very interesting to compare water savings to greenhouse gas emissions for artificial turf versus natural grass. If, as one may hypothesize, artificial turf uses less water but causes more greenhouse gas emissions, then another complex decision arises: Are emissions reductions or water use reductions prioritized? If the turf is installed for environmental reasons, is it better to save water or to reduce emissions? How much of the energy used in manufacturing artificial turf must come from renewable sources for it be as carbon intensive as natural grass? Unfortunately, we did not have time to investigate this topic. Future researchers may wish to delve into this issue by using energy as an impact category.

Sensitivity and Uncertainty Analysis

After completing the base calculations, we performed a sensitivity analysis to determine the most sensitive inputs in each of our impact categories for turf and sod. A sensitivity analysis accomplishes this by changing a single input in order to see the effect of such changes on the overall output of a model. We performed a local sensitivity analysis, in which we varied one input at a time by +10% and -10% of its base value, while keeping all other inputs fixed at their base value, as seen in the figures further below in this section. Note that neither harvesting nor fertilizer were included in the water footprint sensitivity analysis for sod because the values were negligible.

The sensitivity analysis also helped account for the uncertainty within our base calculations. For example, our calculations face uncertainty because we used secondary sources, used the EIOLCA tool, and also because of the many different values for costs and water footprints on the web. To further elaborate, the EIOLCA tool's categories are very broad and sometimes display the life cycle impacts for multiple processes, beyond the one we wish to focus on. For instance, as stated in the EIOLCA Discussion section, because "Turf Production" is not one of the categories in the tool, we had to refer to the "Carpet and Rug Mills" sector. Although these processes may be similar, they are not the same, which adds uncertainty to the values that were collected in this fashion. As for the varying data on the web, our team took average values of the data we found, which lessens variability but adds another aspect of uncertainty because we are not aware of the distribution of the values. The local sensitivity analysis performed does not eliminate the uncertainties mentioned, but does account for them.

We were able to reduce an interpretation phase uncertainty of changes in market values and the technical changes in future production methods by discounting costs. The discounted values are also the ones used in the sensitivity analysis.

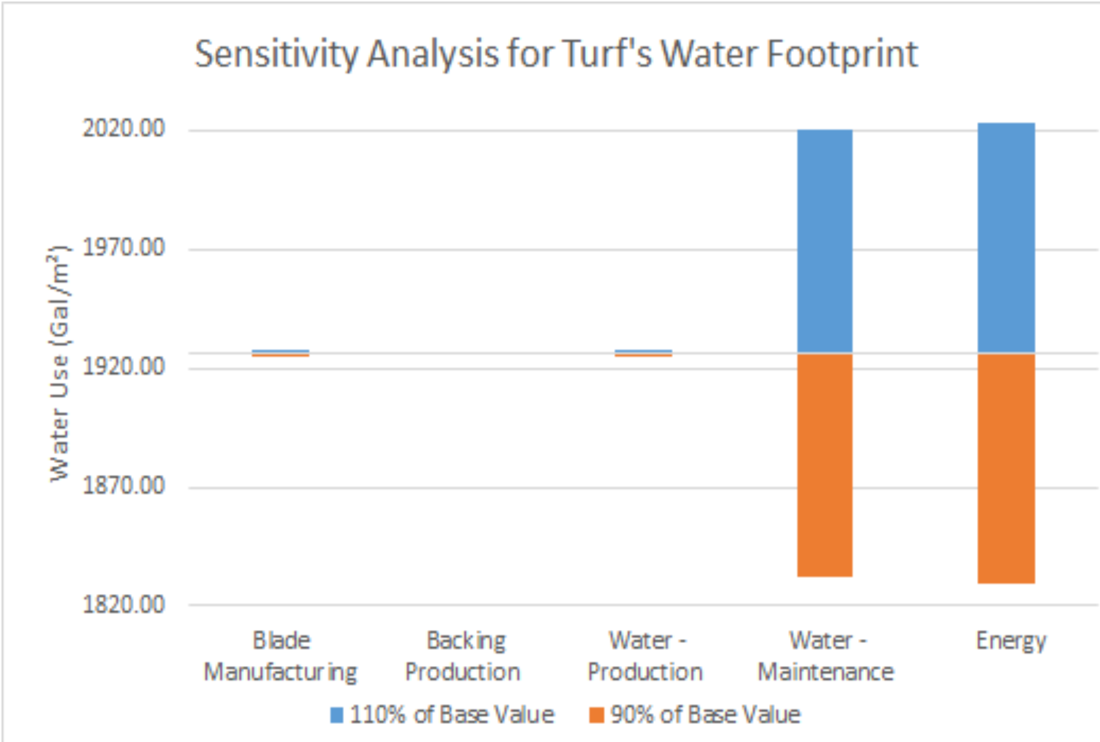

Figure 3: Sensitivity analysis for turf's lifecycle water footprint

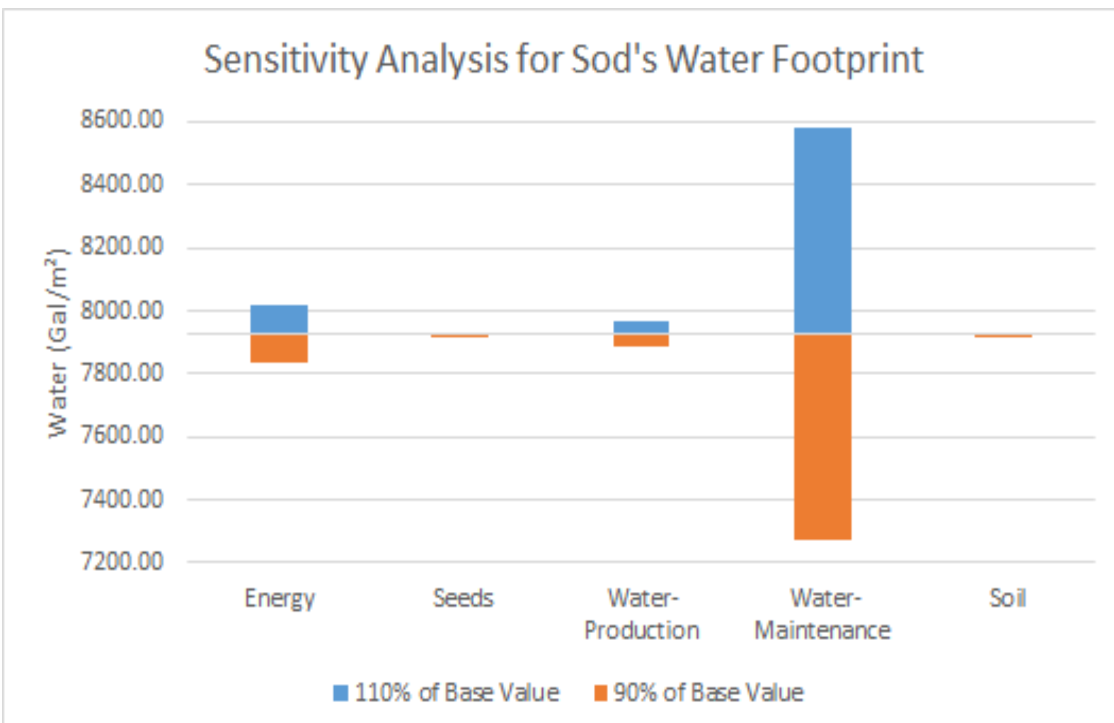

Figure 4: Sensitivity analysis for sod's lifecycle water footprint

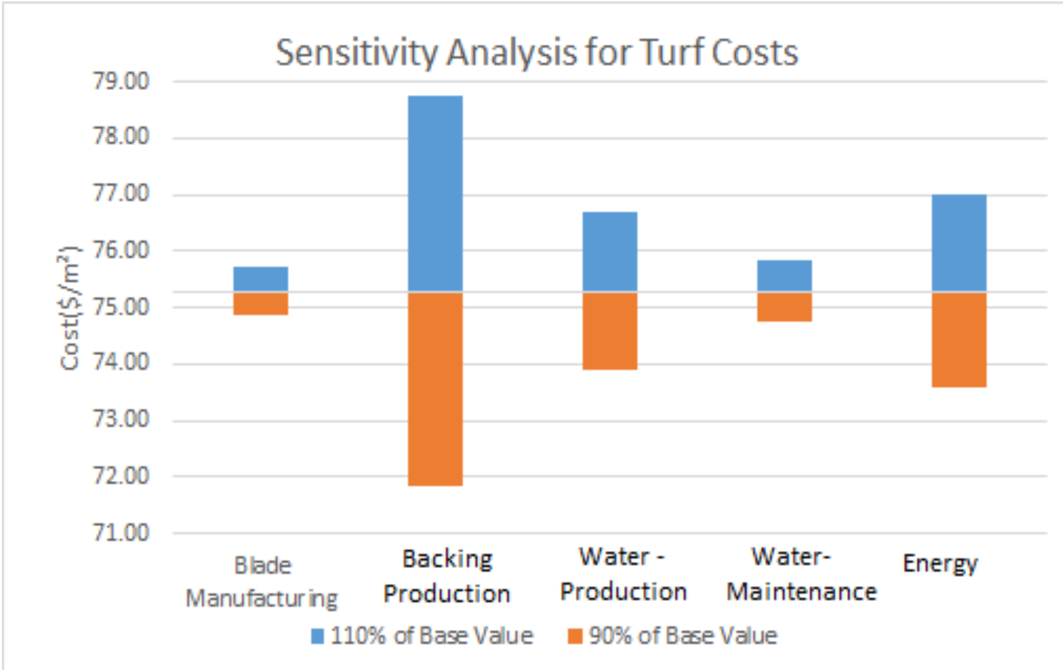

Figure 5: Sensitivity analysis for turf's lifecycle costs

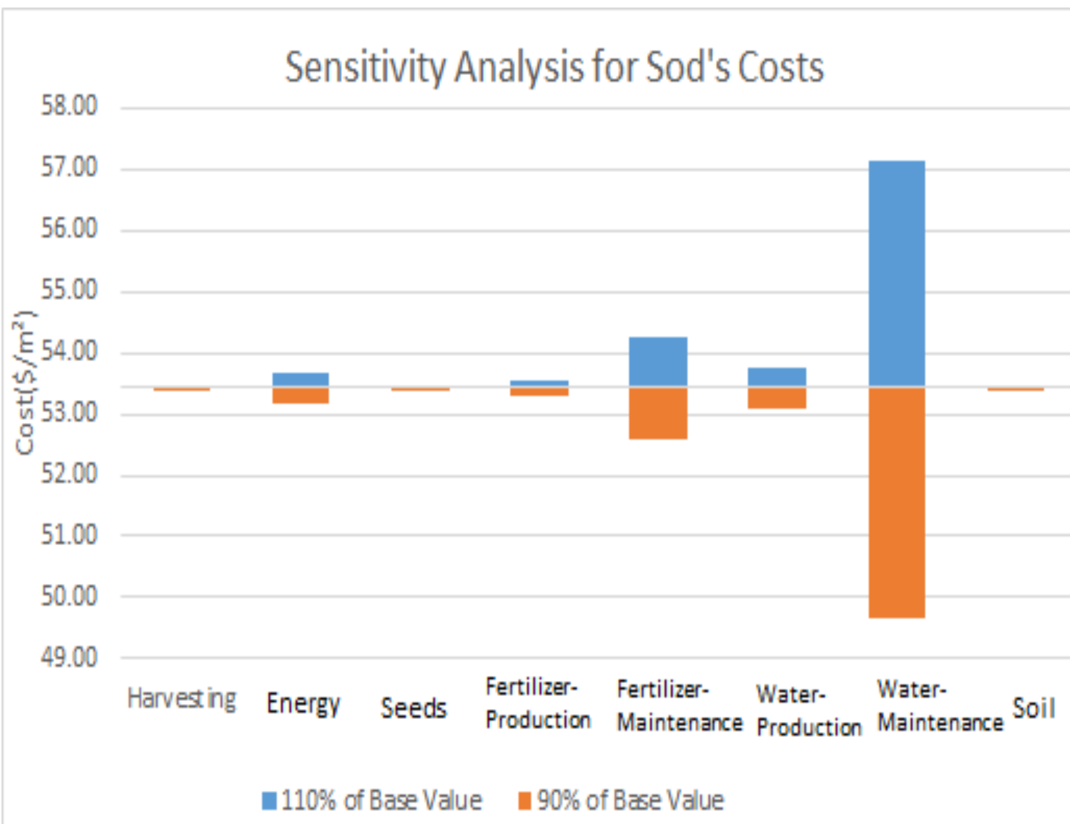

Figure 6: Sensitivity analysis for sod's lifecycle costs

Summary of Results and Conclusions

Based on our calculations, the cost of turf production is $75.29/m² compared to $53.41/m² for sod. In addition, the total water needed to maintain artificial turf is 1926 gal/ m² compared to 7926 gal/m² for sod. Clearly, from a water perspective, artificial turf will use less in the long run. However, when considering the greater cost of turf manufacturing and the impacts of its artificial materials this choice becomes less clear. Also, an individual living in an area with ample rainfall may find that turf is an inferior choice, environmentally as well as economically, based on their personal conditions. It is important to note that other factors such as chemical leaching and ecosystem disruption which are possible side-effects of artificial turf, have not been included in this analysis. Turf and sod may both be inferior to other, newer landscaping options such as xeriscape which uses both fewer artificial materials as well as less water.

Sensitivity Interpretation

From our sensitivity analysis above, we can easily see what system inputs affect our results the most. For the artificial turf, water maintenance and energy have the largest impact on the water footprint of turf, each leading to about a 100 gallon change when adjusting their inputs by 10%. For natural grass sod, water maintenance is by far the input with the largest impact on its water footprint, which leads to about a 650 gallon change when adjusting its input by 10%. At first glance these may seem like fairly large changes in water use for both of the products. However, if we were to increase all of the turf values by 10% and also decrease the sod values by 10%, we would find that the turf would still use about 5000 gallons per square meter less water than sod. So in the end, these uncertainties don't bare much effect on the final result of our analysis.

As for the sensitivity of inputs to lifecycle costs, backing production has the largest impact for artificial turf, leading to about a $3.50 change when adjusting its input by 10%. For the sod, water maintenance is, again, the input that affects the cost of sod the most, leading to about a $3.60 change when adjusting its input by 10%. Again, if we were to increase all of the sod values by 10% and decrease all of the turf values by 10%, the sod would still come out to be about $10 per square meter cheaper than the turf. This dollar amount adds up quickly when installing large amounts of turf or sod for your lawn, and so these uncertainties also do not bare much of an effect on the final result of our analysis.

Overall Discussion

From our analysis we learned two things: artificial turf is a more expensive product, and natural grass sod is a more water intensive product. Therefore, the decision of which product to choose depends solely upon the consumer's answer to the following question: what matters more, cost or water savings? The answer may vary spatially and temporally. For example, someone in drought-stricken California has significantly greater interest in conserving water than someone in rain-rich Portland. To explain temporal variation, someone who just lost his job may be more interested in natural grass--it is cheaper, especially upfront. Someone purchasing water after LADWP increases its rates may be more interested in artificial turf--water and monetary savings in the long-term will be greater. For an institution like UCLA, which has an extremely ambitious goal to reduce per capita potable water use by 36% by 2025, installing turf makes sense. Almost all scenarios for reducing water use will require some investment, and the gallons of savings to dollar of investment ratio for artificial turf is much better than for expensive strategies like desalination.

Limitations of Current Work

Artificial turf is still a relatively new technology and as such material inventories are not standardized nor readily available. There are hundreds of turf companies, with varying manufacturing methods and materials used. One of our greatest limitations was finding accurate and trustworthy data to depict these less commonly used materials (or in the case of some common materials, a rare context for use.) The artificial grass blades used in the manufacturing process of turf, for instance, may be made of nylon fabrics or woven polyethylene. However, when using LCA databases for quantifiable measurements of the overall resources which go into making these synthetic fibers (either based on cost of materials, weight of materials, water use etc.) the options provided are vague and difficult to match with our specific indices. As so, our results and calculations may become skewed due to inventory components which are more sensitive to change.

Another limitation is assigning costs which reflect the true value of resources and their use. These costs can be incredibly variable depending on location, time of year, data source, and consistency of record keeping. Specifically in regards to our study, the cost of water and electricity vary by region, by season, and even at times of day (depending on the region and which energy sources are available to supply the grid with power). To account for this variability and normalize our data we took averages of the available data. In the case of water, we used the tier pricing (for residential use) as recorded by LADWP, averaged over the course of a year. In the case of energy, we used the average cost per kilowatt hour for the state of California ($0.15/kwh) from EIA (EIA, 2016). Where if the turf manufacturing facility was located in Los Angeles, for example, the cost would be much higher, averaged at around $0.21 per kilowatt hour of electricity use (Hanak, Davis, 2006).

Our current research has been constrained by our limited research timeframe (under 10 weeks of study) and lack of funding. Due to these constraints, our analysis only includes the most relevant manufacturing processes and stops after stage two. With more time and resources we could access private data sources, expand our area of study, and more thoroughly analyze elements from stage three, such as the complexities of tire manufacturing for the recycled crumb rubber often used as filler for artificial turfs (EPA, 2016).

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Team Member Contributions: Previously turned in via CCLE and Excel.

Appendix

First and Second Tier Rates				
	2015		2016	
	Tier 1	Tier 2	Tier 1	Tier 2
January	$4.863	$6.029	$4.654	$6.415
February	$4.863	$6.029	$4.654	$6.415
March	$4.863	$6.029	$4.654	$6.415
April	$4.832	$6.162	$4.630*	$6.405*
May	$4.832	$6.162		
June	$4.832	$6.162		
July	$5.014	$6.229		
August	$5.014	$6.229		
September	$5.014	$6.229		
October	$4.554	$6.208		
November	$4.554	$6.208		
December	$4.554	$6.208		

Taken from: https://www.ladwp.com/ladwp/faces/ladwp/aboutus/a-financesandreports/a-fr-waterrares/a-fr-wr-scheduleresidential