Optimization Model For Selecting The Most Environmentally Friendly Treatments of Cotton T-shirts

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1 Introduction

As a member of Tzu Ching, a volunteer organization at UCSD, I learn to value the importance of environmental protection. To advocate environmental protection, I participated in an Earth Day event at Balboa Park in San Diego and passed out flyers to inform people about how significant the environmental impact of different industries is, especially the fashion industry. Fast fashion companies, such as Zara, Forever 21, H&M, produce and sell hundreds of millions of t-shirts to customers every year, but both t-shirts manufacturers and customers rarely know how much impact these t-shirts have on environment in their life cycles. Fertilizers used for cotton production and dye chemicals that contain toxic substances, such as lead and mercury, can contaminate the environment significantly. Approximately 2700 liters of water are used to produce cottons for just one cotton t-shirt. About 50 kilograms of carbon dioxide are emitted during the process of weaving, knitting, washing, and drying t-shirts, and they contribute greatly to global warming.

Seeing how inefficient the water use in cotton cultivation is and how much pollution producing and treating t-shirts cause, I am interested in exploring how to build a model that can find the process of producing, manufacturing, distributing, and using cotton t-shirts with the least environmental impact. This way, I can recommend the most environmentally friendly treatments of cotton t-shirts to manufacturers and shoppers and further promote the idea of environmental protection.

2 Features For Model

According to [3], cotton production, cotton manufacturing, distribution, and consumer use phases are the main contributors to the environmental impacts in the life cycle of the cotton t-shirt. In these four major phases, various resources are consumed, such as water, coal, steam, electricity, and various wastes are produced, such as carbon dioxide, fly ash, waste water, coal cinder, and chemical wastes. According to [3], energy use, chemical wastes, and water use are main contributors to most impact categories. Since energy use such as consumption of electricity would ultimately generate carbon dioxide, I exclude energy use and choose water consumption, chemical wastes, and carbon dioxide emission as three features for my model.

3 Data For The Model

The steps in these four major phases in the life cycle of cotton t-shirts are as follow: (1) organic or conventional cottons are grown and different pesticides are applied for cotton cultivation; (2) cottons go through weaving, knitting, dyeing in different methods with different dye chemicals applied, printing, print afterwashing, dye finishing, and other cotton treatments steps and are manufactured into t-shirts; (3) t-shirts are delivered to stores or customers by cars, ships, or planes; (4) customers wear cotton t-shirts, wash them using washing machine of different ages with different amount of detergent applied, dry them, and repeat this process.

The data of my model includes amount of water consumption, carbon dioxide emission, and chemical wastes in all steps identified in four major phases of cotton t-shirts. Since I do not find a database that contains complete data of those features in all steps identified above, I collect data of three features from different sources and combine them into a database in excel sheet. Carbon dioxide emission data is collected from papers published by Journal of Integrative Environmental Sciences, and water consumption data is collected from blogs of water consumption in textile industry, so they are relatively reliable. But chemical wastes data is collected from blogs of personal instructions on what dye chemicals to use when dyeing t-shirts by self, so they are less reliable.

The database of water consumption, carbon dioxide emission, and chemical wastes in four major phases of the cotton t-shirt's life cycle is shown in figure 1, figure 2, figure 3, and figure 4. Water consumption and carbon dioxide data is in the unit of gallons per cotton t-shirt, and chemical wastes data is in the unit of kilograms per cotton t-shirt. The lower and upper bounds of total amount of three features in each phase are also calculated.

Growing Resources	Water Use	Water Low	Water Hig	CO2 Emiss	CO2 Low	CO2 High	Chemical '	Chemical I	Chemical High
Agriculture									
Cotton									
Organic Cotton	660	660	660						
Non-organic Cotton	290	290	290						
Pesticide	0.0044531:	0.004453	0.004453				0.002969		
Imidacloprid							1.56E-05	1.56E-05	1.56E-05
Centric							1.171875e	1.17E-05	1.95E-05
Transform							1.17E-05	1.17E-05	1.17E-05
Orthene							8.375e-5 -	8.38E-05	9.38E-05
Bidrin							4.6875e-5	4.69E-05	6.25E-05
Vydate CL-V							9.375e-5 -	9.38E-05	0.000125
Diamond							3.125e-5 -	3.13E-05	4.69E-05
Acephate							3.13E-05	3.13E-05	3.13E-05
Mixture of acephate and imidacloprid							4.69E-05	4.69E-05	4.69E-05
Aphids							3.91E-05	3.91E-05	3.91E-05
Intruder							9.38E-06	9.38E-06	9.38E-06
Aggregates	290.00445:	290.0045	660.0045	0	0	0	0.0000093	9.38E-06	1.25E-04

Figure 1: Cotton Production Phase

Fabric Manufacturing	Water Us	Water Lo	Water Hi	CO2 Emis	CO2 Low	CO2 High	Chemical	Chemical	Chemical High
Weaving	0.1718 - :	0.1718	20.1211	12.6	12.6	12.6			
Knitting	0.6872 - 1	0.6872	14.9339	11.27	11.27	11.27			
Dyeing/Printing/Print after washing/Finishing				2.1 kg of	2.1	2.1			
Dye Process							0.1194	0.1194	0.1194
Chemicals									
Salt							0.03996 -	0.03996	0.07992
Caustic potash							0.0018601	0.00037	0.0026
Fiber-reactive dye poweder							0.000372(	0.00037	0.00149
Zinc							varied frc	0.00803	0.04742
Copper							Cu varies	0	0.01688
Dyeing Methods									
Beam	5.7269 - 6	5.7269	6.6079						
Beck	8.0176 - 9	8.0176	9.2511						
Jet	6.8722 - 7	6.8722	7.9295						
Jig	3.4361 - 3	3.4361	3.9648						
Paddle	10.022 - 1	10.022	11.5639						
Skein	8.5903 - 9	8.5903	9.9119						
Stock	5.7269 - 6	5.7269	6.6079						
Pad-batch	0.5727 - 0	0.5727	0.6608						
Package	6.2996 - 7	6.2996	7.2687						
Continuous bleaching	5.7269 - 6	5.7269	6.6079						
Indigo dyeing	0.2863 - 1	0.2863	1.9824						
Printing Process	0.859 - 0.!	0.859	0.991						
Print afterwashing	3.7797 - 4	3.7797	4.3612						
Dye Finishing Process	0.1718 - 0	0.1718	0.1982						
Dye Manufacturing Process	15.91927:	15.9193	15.9193						
Petroleum							1.59 gallc	1.59	1.59
Other chemicals							0.159 gal	0.159	0.159
Other Cotton Treatment									
Desizing	0.0859 - 0	0.0859	0.793						
Scouring	0.6586 - 1	0.6586	1.685						
Bleaching	0.0859 - 4	0.0859	4.9229						
Mercerizing	0.0344 - 0	0.0344	0.0396						
Aggregates	21.16504	21.165	95.115	28.97	28.97	28.97	0.1194 - 1	0.1194	1.7094

Figure 2: Manufacturing Phase

Transportation	Water Use	Water Low	Water Hig	CO2 Emiss	CO2 Low	CO2 High	Chemical '	Chemical I	Chemical High
Packaging for shipping									
by shipping				3.07 kg of	3.07	3.07			
by plane				6.5 kg of c	6.5	6.5			
Aggregates				3.07-6.5	3.07	6.5			

Figure 3: Distribution Phase

Use-Phase						Water Use	Water Low	Water Hig	CO2 Emiss	CO2 Low	CO2 High	Chemical \	Chemical I	Chemical High
	Washing Machine													
		New	Medium Heat			12.9444	12.9444	12.9444	1.875 kg c	1.875	1.875			
		5 years olc	Medium Heat			17.4354	17.4354	17.4354	2.16 kg cc	2.16	2.16			
		10 years o	Medium Heat			22.1905	22.1905	22.1905	2.36 kg co	2.36	2.36			
		20 years o	Medium Heat			35.3991	35.3991	35.3991	2.64 kg co	2.64	2.64			
		30 years o	Medium Heat			47.551	47.551	47.551	2.90 kg co	2.9	2.9			
		Chemicals												
			Detergent											
				Size of Load										
					Small/Medium							0.007813	0.007813	0.007813
					Large							0.023438	0.023438	0.023438
					Full							0.039063	0.039063	0.039063
	Dryer													
		Heat Level												
			30Â°C						0.6 kg CO:	0.6	0.6			
			40Â°C, dried on a line						0.7 kg CO:	0.7	0.7			
			40Â°C, tumble dried						2.4 kg CO:	2.4	2.4			
			60Â°C, dried in combined washer/drier						3.3 kg CO:	3.3	3.3			
Aggregates						12.9444 -	12.9444	47.551	2.475 - 6.2	2.475	6.2	0.007813 -	0.007813	0.039063

Figure 4: Customer Use Phase

4 Scaling Function

Selection of the most environmentally friendly process of producing, manufacturing, distributing, and using cotton t-shirts requires a way of measuring impact level of water consumption, carbon dioxide emission, and chemical wastes in each of four phases. Hence, a scaling function is developed.

Given a phase $p \in$ {cotton production, manufacturing, distribution, consume use} and $\{\mathrm{w}_p, co_{2,p}, c_p\}$, which are the amount of water consumption, carbon dioxide emission, and chemical wastes produced by the cotton t-shirt in phase p, for each $y_p \in \{\mathrm{w}_p, co_{2,p}, c_p\}$, the scaling function finds a impact score c on a scale of 1 to 10 such that

$$(c-1) \cdot \frac{(Y_{p,max} - Y_{p,min})}{10} < y_p - Y_{p,min} \leq c \cdot \frac{(Y_{p,max} - Y_{p,min})}{10}, \tag{1}$$

$$with\ c \in Z^+\ and\ 1 \leq c \leq 10 \tag{2}$$

where $Y_{p,max}$ and $Y_{p,min}$ are the upper and lower bound of y_p.

The algorithm of this scaling function is as follows: (1) $Y_{p,max}$ and $Y_{p,min}$ values of three features in each phase are stored as two different collections; (2) given the phase p in which the cotton t-shirt's environmental impact is evaluated and the values of three features $\{w_p, co_{2,p}, c_p\}$ in phase p, the function uses p to extract the corresponding $Y_{p,max}$ and $Y_{p,min}$ values from collections; (3) it calculates the difference between each input value and its corresponding lower bound $y_p - Y_{p,min}$; (4) it calculates the difference between upper and lower bound of each feature $Y_{p,max} - Y_{p,min}$ and divides it evenly into 10 bins that are indexed by c with c $\in Z^+$ and $1 \leq c \leq 10$; (5) the function runs through iterations and checks which bin c each $y_p - Y_{p,min}$ falls in; (6) Once such bin c is found, c is returned as the environmental impact score of the corresponding feature in the phase p. The higher the score c, the larger the impact. The lower the score c, the less the impact; (7) the function returns three environmental impact scores as an collection $\{c_1, c_2, c_3\}$, one impact score for each feature.

5 Optimization Model

To compare the overall environmental impact of cotton t-shirts in each phase, three impact scores calculated by the scaling function need to be aggregated into one score to indicate the degree of overall impact. For simplicity, I assume that there is a linear relationship between the impact level of each feature and the overall impact level, and hence, a weight should be given to each impact score. However, there is little information about how to calculate the weight of each feature. In this situation, linear optimization model is derived to find the optimal weights for three impact scores such that the overall impact score computed is the smallest possible one that the cotton t-shirt can get.

The general linear optimization equation is as follow:

$$\min_{x} c^T x \tag{3}$$

$$\text{s.t.} \sum_{i=0}^{n} x_i = 1 \tag{4}$$

where $c \in R^n$ and x is $n \times 1$ vector.

Using impact scores $\{c_1, c_2, c_3\}$ calculated by the scaling function, I derive a more specific optimization equation as follows:

$$\min_{(\alpha,\beta,\gamma)} (c_1, c_2, c_3)(\alpha, \beta, \gamma)^T \tag{5}$$

$$\text{s.t.} \begin{cases} \alpha + \beta + \gamma = 1 \\ 1 \leq (c_1, c_2, c_3)(\alpha, \beta, \gamma)^T \leq 10 \\ \frac{1}{3} - \frac{1}{10} \leq \alpha, \beta, \gamma \leq \frac{1}{3} + \frac{1}{10} \end{cases} \tag{6}$$

where α, β, γ are the weights of three environmental impact scores and $(c_1, c_2, c_3)(\alpha, \beta, \gamma)^T$ is the overall impact score that the model tries to minimize using optimal solutions of α, β, γ. Since water consumption, carbon dioxide emission, and chemical wastes are chosen as only contributors to overall environmental impact, the weights of their impact scores should sum up to 1. If in other cases, $\alpha + \beta + \gamma = k \neq 1$, then weights (α, β, γ) can be replaced with $(\frac{\alpha}{\alpha+\beta+\gamma}, \frac{\beta}{\alpha+\beta+\gamma}, \frac{\gamma}{\alpha+\beta+\gamma})$. In this case, $\frac{\alpha}{\alpha+\beta+\gamma} + \frac{\beta}{\alpha+\beta+\gamma} + \frac{\gamma}{\alpha+\beta+\gamma} = 1$ and the condition is satisfied. $1 \leq (c_1, c_2, c_3)(\alpha, \beta, \gamma)^T \leq 10$ defines the range of overall environmental impact score to be 1 to 10. Since each feature has nonzero degree of impact on environment and none of them impact environment solely, then $0 < \alpha, \beta, \gamma < 1$. In one situation, each feature impacts environment equally, so $\frac{1}{3}$ is chosen as the midpoint of each weight's range and $\exists a$ such that $\frac{1}{3} - a < \alpha, \beta, \gamma < \frac{1}{3} + a$. Based on the condition that $0 < \alpha, \beta, \gamma < 1$, the bound of a is derived as $0 \leq a < \frac{1}{3}$. For simplicity, $a = \frac{1}{10}$ is chosen and the final bound $\frac{1}{3} - \frac{1}{10} \leq \alpha, \beta, \gamma \leq \frac{1}{3} + \frac{1}{10}$ for weights is derived.

By comparing smallest possible overall scores of all cotton t-shirts in a phase, the t-shirt with the minimum score could be determined to be the one that has the least environment impact in that phase. Then, the treatments the lowest scoring t-shirt gets are the most environmentally friendly treatments of the t-shirt in that phase and could be recommended to t-shirts manufacturers and users.

6 Relevant Work Done

[1] use life cycle assessment to evaluate the cotton t-shirt's impact on environment due to conventional and organic cotton cultivation. It summarizes that the conventional cultivation needs more machinery, pesticides, and detrimental chemicals, while organic cotton cultivation uses more manual work and natural ways of controlling the pest. The life cycle assessment performed shows that conventional cotton cultivation has much more significant impact, particularly on global warming effect. Moreover, organic cultivation takes up more land area and consumes more water, but authors conclude that these costs are worthy because organic cotton cultivation produces much less detrimental chemical wastes from pesticide use.

[2] conducts life cycle assessment of flame retardant cotton curtains. Authors propose an environmentally friendly disposal process of the end-of-life phase of flame retardant textiles. Then, they run life cycle assessment model to calculate its impact in each category and compare the impact of the proposed end-of-life disposal process with that of the usual disposal process. The results of comparisons show that the proposed disposal process reduces the environmental impact in all impact categories.

[3] performs life cycle assessment of cotton t-shirts in China. In the article, authors identify cotton cultivation, textile manufacturing, and consumer use as three major phases in the life cycle of a

t-shirt. They select energy, material, emission to air, emission to water, solid waste as their features. With the result from life cycle impact analysis, authors evaluate the environmental impact of cotton t-shirts and find areas of great environmental impact in China.

These three projects all use life cycle assessment(LCA) model to evaluate the environmental impact of cotton t-shirts or cotton curtains. LCA model takes in the amount of raw materials used and the amount of outputs, such as carbon dioxide emissions, of one phase and uses some assessment methods to quantify impact on broader categories such as climate change, acidification, terrestrial eutrophication. My model is different from LCA model in that after taking environmental inputs and outputs, it assigns a impact score between 1 to 10 to three features I choose, rather than quantify their impacts on broader categories. Moreover, these scores are aggregated into one overall impact score to represent the overall impact level, while LCA model does not aggregate impacts in multiple categories into one overall impact level. Moreover, my optimization model finds the most environmentally friendly treatments of cotton t-shirts in each phase, which is not achieved by LCA model used in the projects above.

7 Computations Involved When Minimizing The Function

Some computations are involved in finding the most and the least environmentally friendly treatments of cotton t-shirts in each phase. The amount of water consumption, carbon dioxide emission, chemical wastes in each step of the phase are stored into three different collections. Then, product function from itertools package in python is used to create all possible $(w_p, co_{2,p}, c_p)$ sequence of three features' data in phase p. Also, I keep track of the corresponding process where the impact happens. Taking all possible $(w_p, co_{2,p}, c_p)$ sequences, the scaling function calculates three environmental impact scores (c_1, c_2, c_3) for three features.

After (c_1, c_2, c_3) for each $(w_p, co_{2,p}, c_p)$ is computed, linprog function in scipy.optimize package in python is used. It takes in the coefficients (c_1, c_2, c_3) of the linear objective function to be minimized $((c_1, c_2, c_3)(\alpha, \beta, \gamma)^T)$, the coefficients $(1, 1, 1)$ of the linear equality constraint on α, β, γ $(\alpha + \beta + \gamma = 1)$, the value of 1 on the right hand side of the linear equality constraint on α, β, γ, and (min, max) pairs $[\frac{1}{3} - \frac{1}{10}, \frac{1}{3} + \frac{1}{10}]$ for each element in (α, β, γ) that defines the bounds on that parameter. The values that linprog function returns include optimal solutions of (α, β, γ) that minimizes the object function while satisfying the constraints and the minimum value of the function $(c_1, c_2, c_3)(\alpha, \beta, \gamma)^T$, which is the minimum overall environmental impact score each cotton t-shirt that gets different treatments can get.

8 Results

I store all possible $(w_p, co_{2,p}, c_p)$ sequences, the values of α, β, γ that minimizes the overall impact score calculated by $(c_1, c_2, c_3)(\alpha, \beta, \gamma)^T$, the minimum overall environmental impact scores, and the corresponding process where the impact happens into a data frame for each phase. The rows in the data frame are sorted by minimum overall impact scores in ascending order. Moreover, plotting tools in python are used to create horizontal bar plots of ascending ordered minimum impact scores, and each bar in the plots is labeled by the corresponding treatments.

If overall impact score $s \in [1, 3.25]$, then the corresponding process is extremely environmentally friendly. If $s \in (3.25, 5.5]$, then the corresponding process is relatively environmentally friendly. If $s \in (5.5, 7.75]$, then the corresponding process is relatively environmentally unfriendly. If $s \in (7.75, 10]$, then the corresponding process is extremely environmentally unfriendly.

The data frame and the plot in figure 5 shows 5 most environmentally friendly processes of producing cotton resources for t-shirts. If the type of cotton needed is conventional, then farmers are recommended to apply 0.38 ounce of Intruder, Transform, Centric, Imidacloprid pesticide to the cotton of enough amount for making one t-shirt. If the type of cotton needed is organic, then farmers are recommended to apply 0.38 ounce of Acephate pesticide. The overall environmental impact scores of these practices are between 1 and 1.3. This range indicates that these practices are extremely environmental friendly.

	Procedure	Data	Score	Weights
21	Conventional, 0.38 ounce Intruder	[290.004453, 0, 9.38e-06]	1.000000	[0.2333333333333333, 0.3333333333333333, 0.433...
13	Conventional, 0.38 ounce Transform	[290.004453, 0, 1.17e-05]	1.000000	[0.2333333333333333, 0.3333333333333333, 0.433...
12	Conventional, 0.38 ounce Centric	[290.004453, 0, 1.95e-05]	1.000000	[0.2333333333333333, 0.3333333333333333, 0.433...
11	Conventional, 0.38 ounce Imidacloprid	[290.004453, 0, 1.56e-05]	1.000000	[0.2333333333333333, 0.3333333333333333, 0.433...
18	Conventional, 0.38 ounce Acephate	[290.004453, 0, 3.13e-05]	1.233333	[0.3333333333333333, 0.43333333333333335, 0.23...

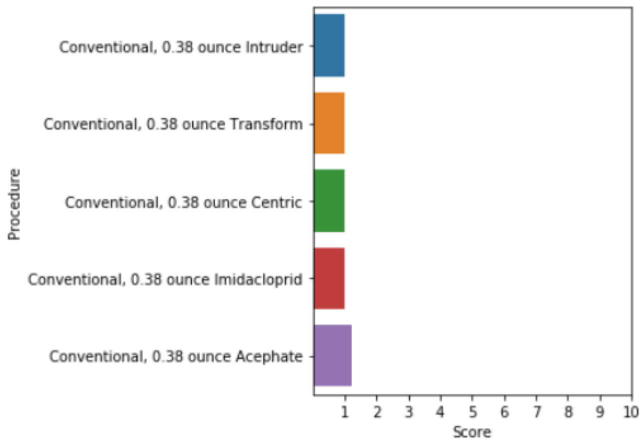

Figure 5: Most Environmental Friendly Treatments in Cotton Production Phase

The data frame and the plot in figure 6 shows 5 least environmentally friendly processes of producing cotton resources for t-shirts. The overall impact scores of these practices are between 4 and 6. This range suggests that the corresponding practices are not extremely environmentally unfriendly nor extremely environmentally friendly. So, if the type of cotton needed is organic, then farmers are recommended to avoid applying 0.38 ounce of Mixture of Acephate and Imidacloprid, Diamond, Bidrin, Orthene, and Vydate CL-V pesticides to cottons of enough amount for making a t-shirt. If there are no other pesticides available, then using those pesticides would not have significant impact on environment.

	Procedure	Data	Score	Weights
8	Organic, 0.38 ounce Mixture of acephate and im...	[660.004453, 0, 4.69e-05]	4.100000	[0.2333333333333333, 0.43333333333333335, 0.33...
6	Organic, 0.38 ounce Diamond	[660.004453, 0, 4.69e-05]	4.100000	[0.2333333333333333, 0.43333333333333335, 0.33...
4	Organic, 0.38 ounce Bidrin	[660.004453, 0, 6.25e-05]	4.433333	[0.2333333333333333, 0.43333333333333335, 0.33...
3	Organic, 0.38 ounce Orthene	[660.004453, 0, 9.38e-05]	5.433333	[0.2333333333333333, 0.43333333333333335, 0.33...
5	Organic, 0.38 ounce Vydate CL-V	[660.004453, 0, 0.000125]	6.100000	[0.2333333333333333, 0.43333333333333335, 0.33...

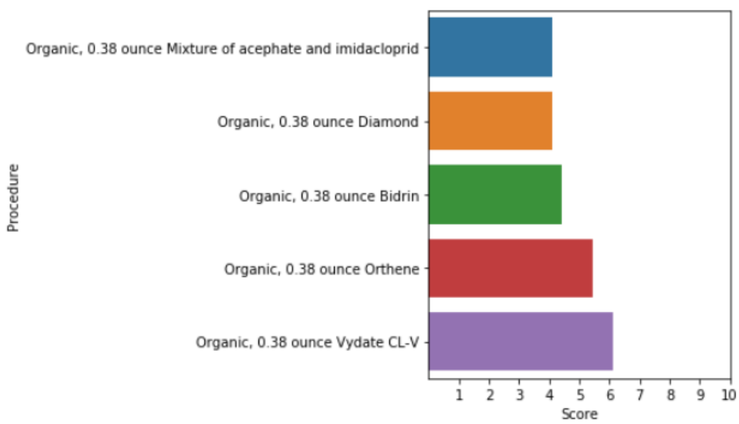

Figure 6: Least Environmental Friendly Treatments in Cotton Production Phase

The data frame and the plot in figure 7 shows 7 most environmentally friendly processes of manufacturing cottons. After weaving and knitting cottons, the manufacturers are recommended to dye cottons in pad-batch dyeing method and apply certain dye chemicals, such as fiber-reactive dye powder, caustic potash, salt, and chemicals that are made of petroleum and contain elements of cupper. After dyeing, printing, print afterwashing, and dye finishing the cotton fibres, if manufacturers want to apply more treatments, they are recommended to desize or mercerize cotton fibres. The environmental impact score of these 7 practices are 2.633, which means those practices are extremely environmentally friendly.

	Procedure	Data	Score	Weights
200	Weaving, Knitting, Pad-batch Dyeing, Printing,...	[80.08197200000001, 28.97, 0.2784]	2.633333	[0.2333333333333333, 0.3333333333333333, 0.433...
198	Weaving, Knitting, Pad-batch Dyeing, Printing,...	[80.08197200000001, 28.97, 0.1208881]	2.633333	[0.2333333333333333, 0.3333333333333333, 0.433...
197	Weaving, Knitting, Pad-batch Dyeing, Printing,...	[80.08197200000001, 28.97, 0.12200156]	2.633333	[0.2333333333333333, 0.3333333333333333, 0.433...
196	Weaving, Knitting, Pad-batch Dyeing, Printing,...	[80.08197200000001, 28.97, 0.19932]	2.633333	[0.2333333333333333, 0.3333333333333333, 0.433...
201	Weaving, Knitting, Pad-batch Dyeing, Printing,...	[80.08197200000001, 28.97, 0.16682186]	2.633333	[0.2333333333333333, 0.3333333333333333, 0.433...

Figure 7: Most Environmental Friendly Treatments in Manufacturing Phase

The data frame and the plot in figure 8 shows 5 least environmentally friendly processes of manufacturing cottons. Their overall impact scores are 6.1. Hence, the corresponding practices are relatively environmental unfriendly. So, after weaving and knitting cottons, the manufacturers are recommended to avoid using skein dyeing, package dyeing, paddle dyeing, or jet dyeing methods and avoid applying dye chemicals that contain element of zinc to dye cotton fibres. After dyeing, printing, print afterwashing, and dye finishing the cotton fibres, if manufacturers want to apply more treatments, they are recommended to avoid scouring or bleaching cottons.

The data frame and the plot in figure 9 shows the environmental impact level of two shipping methods of t-shirts distribution. By comparison, delivering t-shirts by ship has less environmental impact than delivering by plane.

The data frame and the plot in figure 10 shows 5 most environmentally friendly processes of washing and drying t-shirts. When washing t-shirts, people are recommended to set the load size to small and the heat level to medium heat. If they want to use drying machine to dry cotton t-shirts, they are recommended to set the drying temperature to 30 Celsius. Or, they are recommended to line-drying t-shirts. The overall impact scores of these practices are between 1 and 1.8, which means those practices are extremely environmentally friendly. Even though new washing machine impacts environment less than 5 and 10 years old washing machine, it is not reasonable to recommend people to buy a new machine because it is not worth spending much money to reduce some degree of environmental impact in this phase.

	Procedure	Data	Score	Weights
150	Weaving, Knitting, Skein Dyeing, Printing, Pri...	[90.22507200000001, 28.97, 1.7094]	6.1	[0.2333333333333333, 0.43333333333333335, 0.33...
241	Weaving, Knitting, Package Dyeing, Printing, P...	[90.819772, 28.97, 1.7094]	6.1	[0.2333333333333333, 0.43333333333333335, 0.33...
157	Weaving, Knitting, Skein Dyeing, Printing, Pri...	[93.46297200000001, 28.97, 1.7094]	6.1	[0.2333333333333333, 0.43333333333333335, 0.33...
122	Weaving, Knitting, Paddle Dyeing, Printing, Pr...	[91.87707200000001, 28.97, 1.7094]	6.1	[0.2333333333333333, 0.43333333333333335, 0.33...
73	Weaving, Knitting, Jet Dyeing, Printing, Print...	[91.48057200000001, 28.97, 1.7094]	6.1	[0.2333333333333333, 0.43333333333333335, 0.33...

Figure 8: Least Environmental Friendly Treatments in Manufacturing Phase

	Shipping Methods	Data	Score	Weights
0	Asia to Europe by ship	[0, 0, 3.07]	1.0	[0.2333333333333333, 0.3333333333333333, 0.433...
1	Asia to Europe by plane	[0, 0, 6.5]	3.1	[0.3333333333333333, 0.43333333333333335, 0.23...

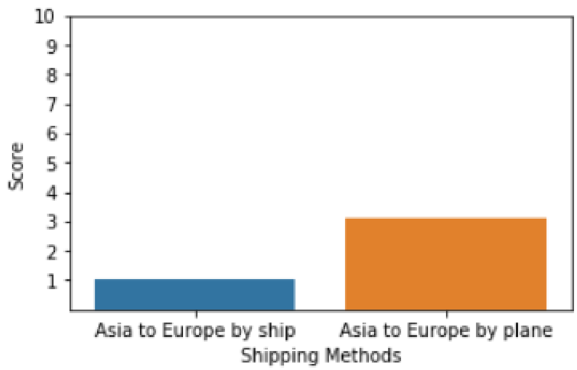

Figure 9: Distribution Phase

The data frame and the plot in figure 11 shows 5 least environmentally friendly processes of washing and drying t-shirts. Their overall impact scores are between 7.7 and 10. This range indicates that those practices have significant impact on environment. When washing t-shirts, people should not set the load size to large or full, unless they want to wash a full load of clothes. When drying t-shirts, people should not set the drying temperature to 40 or 60 Celsius, which are medium and high heat level. Moreover, they should not set the drying mode to tumble dry or dry the t-shirts in combined washer or drier. Here, given 20 and 30 years old washing machines have significant environmental impact, if people having 20 or 30 years old washing machine feel a need to buy a new one, then they are recommended to do so.

	Procedure	Data	Score	Weights
0	New Machine Medium Heat, Small Load, 30 Celsius	[12.9444, 0.0078125, 2.475]	1.000000	[0.2333333333333333, 0.3333333333333333, 0.433...
1	New Machine Medium Heat, Small Load, 40 Celsiu...	[12.9444, 0.0078125, 2.575]	1.000000	[0.2333333333333333, 0.3333333333333333, 0.433...
12	5 Yrs Old Machine Medium Heat, Small Load, 30 ...	[17.4354, 0.0078125, 2.7600000000000002]	1.233333	[0.2333333333333333, 0.3333333333333333, 0.433...
13	5 Yrs Old Machine Medium Heat, Small Load, 40 ...	[17.4354, 0.0078125, 2.8600000000000003]	1.566667	[0.2333333333333333, 0.43333333333333335, 0.33...
25	10 Yrs Old Machine Medium Heat, Small Load, 40...	[22.1905, 0.0078125, 3.0599999999999996]	1.800000	[0.2333333333333333, 0.43333333333333335, 0.33...

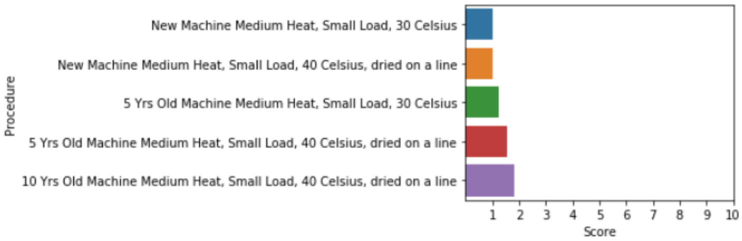

Figure 10: Most Environmental Friendly Treatments in Customer Use Phase

	Procedure	Data	Score	Weights
46	20 Yrs Old Machine Medium Heat, Full Load, 40 ...	[35.3991, 0.0390625, 5.04]	7.700000	[0.3333333333333333, 0.2333333333333333, 0.433...
55	30 Yrs Old Machine Medium Heat, Large Load, 60...	[47.551, 0.0234375, 6.199999999999999]	7.833333	[0.2333333333333333, 0.43333333333333335, 0.33...
47	20 Yrs Old Machine Medium Heat, Full Load, 60 ...	[35.3991, 0.0390625, 5.9399999999999995]	8.700000	[0.43333333333333335, 0.2333333333333333, 0.33...
58	30 Yrs Old Machine Medium Heat, Full Load, 40 ...	[47.551, 0.0390625, 5.3]	9.133333	[0.2333333333333333, 0.3333333333333333, 0.433...
59	30 Yrs Old Machine Medium Heat, Full Load, 60 ...	[47.551, 0.0390625, 6.199999999999999]	10.000000	[0.2333333333333333, 0.3333333333333333, 0.433...

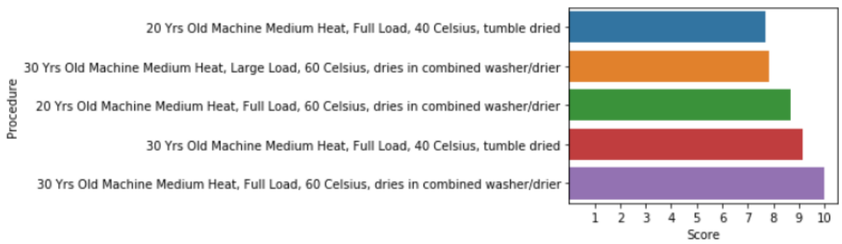

Figure 11: Least Environmental Friendly Treatments in Customer Use Phase

9 Further Improvements

Since I collect my data from different sources and some of them are not very reliable, I want to find a more complete database of these impact features and collect data of three features in each phase from more reliable sources. Moreover, since I do not find information about how to assign weights to each impact score, I choose $[\frac{1}{3} - \frac{1}{10}, \frac{1}{3} + \frac{1}{10}]$ as bounds for α, β, γ. In the future, I hope to do more research on this part and derive more accurate bounds for weights of three impact features. After I presented my project in lecture on Friday in week 10, one student suggested me to research on the cost of performing different treatments in each phase. Her suggestion inspires me to consider how cost of different treatments can affect the weights of impact scores. Lastly, energy consumption can be included as one feature and used by a more refined optimization model for finding the most environmentally friendly treatments of cotton t-shirts in each phase.

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