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Sustainability Assessment of Proctor and Gamble using Fuzzy Logic

ChE 447: Sustainability and Pollution Prevention

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Abstract

The sustainability of Proctor and Gamble was assessed using the method of fuzzy logic. Nineteen basic indicators were chosen, and data was collected from Proctor and Gamble, and other corporations in the household and personal products industry. Basic indicators for Proctor and Gamble were normalized against this data, and the fuzzy and crisp values were calculated. The fuzzy values of these basic indicators were used to evaluate secondary indicators: WEALTH, KNOW, HEALTH, POLIC, WATER, LAND, and AIR. Rule bases were generated, and fuzzy and crisp values were determined for each secondary indicator. Using the crisp values of these secondary indicators, and generated rule bases, primary indicators ECOS and HUMS were calculated. Finally, OSUS was calculated using the fuzzy values of ECOS and HUMS. The fuzzy value of OSUS is: I(.017), I(.003), I(.002), I(.010), I(.056), I(.010), I(.0195), I(0.161), FH(.008), FH(.007), FH(.001), FH(.001), FH(.027) and FH(.022). The crisp value of OSUS is 0.29. The sustainability of Proctor and Gamble is intermediate, but may be improved with the improvement of ecological indicators.

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Introduction

Fuzzy logic is a method introduced by Latfi Zadeh in 1965, which allows the topic being evaluated to have degrees of belonging, as opposed to classic logic, which says a topic either belongs, or it does not. For example, fuzzy logic can be used to describe the state of biodiversity for a country, assigning it a linguistic value of “medium,” with a 0.7 “degree of belonging,” instead of just completely good or bad. This method provides more realistic assessments, for topics such as sustainability, where a number of factors are considered using data that is not always uniform across different corporations. The sustainability of Proctor and Gamble was evaluated, as it compared with other corporations in the household and personal goods industry, including Avon Products, Colgate Palmolive, and Estee Lauder.

Proctor and Gamble (P&G) is a Fortune 500 corporation (#22) founded in 1837. They operate in over eighty countries and markets over three-hundred brands. They produce a wide range of products, including soaps, toothpaste, potato chips, shampoo, and batteries. The manufacturing of these products require a large amount of money, raw materials, waters, chemicals, etc. Because of the resources used for these products, P&G was a good corporation choice to evaluate sustainability. Hence why this corporation, and industry, was chosen to evaluate its’ sustainability, as it pertains to money (WEALTH), employee knowledge (KNOW), employee health (HEALTH), political involvement (POLICY), effect on biodiversity (BIOD), effect on water (WATER), effect on land (LAND), and effect on air (AIR).

Data was collected to serve as basic indicators, which describe each secondary indicator: WEALTH, KNOW, HEALTH, POLICY, BIOD, WATER, LAND, and AIR. Using the indicators

pertaining to the environment, ecological sustainability (ECOS) was assessed; the same was done for indicators pertaining to human sustainability (HUMS). Finally, overall sustainability (OSUS) was calculated using ECOS and HUMS.

Model Description

Basic Indicators

Basic indicators are used to evaluate secondary indicators, WEALTH, KNOW, HEALTH, POLIC, WATER, LAND, and AIR. Biodiversity was not used, because it is not significantly applicable to the operations of this corporation. Most of the basic indicators were made intrinsic such that comparisons could be made between large corporations, like P&G, and small corporations, such as Avon Products. It should be noted that the amount of waste produced was used to normalize a number of the ECOS basic indicators because the amount of production could not be found for many corporations listed in this report. Using the amount of production would have been optimal. Target values are chosen from data collected on multiple companies in the household and personal products industry. Zero was used as the maximum value for all "better high" indicators. Tables 1 through 7 lists the basic indicators chosen to evaluate each secondary indicator.

WEALTH

WEALTH
*Net sales (**NETSALES**)*
*General operating expenses (**GENOP**)*
*Market cap (**MARCAP**)*
*Number of common shareholders of record (**COMSHARE**)*

Table 1: Basic indicators used to evaluate secondary indicator WEALTH

Net sales were used to measure wealth because this corporation sells consumer products, and therefore thrives on how much of its products are sold. Without sales, the corporation would not continue, because such corporations use their sales revenue to purchase more raw materials, pay their employees, and also to reel in investors. How much a corporation sells is a good indicator of whether a corporation can expand, or even if a corporation can

continue producing the same amounts they did a year ago. For this indicator, higher is better. To make the net sales data intrinsic, it was divided by the number of employees ($/employee). The minimum value for complete sustainability is $330,000 per employee.

General operating expenses indicate how much of a corporation's sales go towards running their factories, paying their employees, and other expenses resulting from daily operations. A sustainable corporation would have a target value for operating expenses, such that enough is allotted for operational use, and there is still enough money to be put in other sectors, such as research and development, green buildings, etc. Data collected for research and development was made intrinsic by dividing by the net sales ($/$). Target values for general operating expenses are 0.6-0.30$/$ for complete sustainability. Minimum and maximum values are 0.2-0.30$/$.

Market capitalization, is the total value of the shares of a corporation. It is calculated by summing the share price times the number of shares outstanding for all the types of shares. It is a good indicator of a corporation's wealth, because it details how much money a corporation makes based on investors. It is also a good indicator of public perception of the corporation, because it is dependent on the number of shares outstanding. Market cap is therefore a good indicator of sustainability, as it pertains to wealth, because it measures the size of the corporation based on its' equity. For this basic indicator, the larger the value is the better. Market cap data was made intrinsic by dividing by the number of employees ($/employee). The minimum value for complete sustainability is $1,683,981/employee.

The number of common shareholders relates to market cap because they both indicate public perception of a corporation. The number of common shareholders is the number of people who have purchased shares in a corporation. Common shareholders, like market cap, increases with perception of a corporation's success or future success. A high number of common shareholders is therefore a good indicator of a corporation's sustainability. For intrinsic values, the number of common shareholders was divided by net sales per million dollars (common shareholder/$MM). The minimum value for complete sustainability is 10.75 shareholders/$MM.

KNOW

KNOW
*Global philanthropic contributions (**PHILANTHROP**)*
*Research and development expenditures (**R&D**)*

Table 2: Basic indicators used to evaluate the secondary indicator KNOW

Global philanthropic contributions were used to evaluate KNOW, because most corporations in the household and personal products industry include donations to educational and research programs in their total contributions. Such programs expand educational tools, assistance, etc., to communities, and thus are a good indicator of KNOW, and sustainability, when high. Increasing knowledge, especially in STEM fields, will increase the knowledge of the potential work force at corporations like P&G, thus fostering new ideas, technologies, etc., in the corporation. To make this data intrinsic, contributions were divided by net sales per thousand dollars ($/$1000). The minimum value for complete sustainability is $1.26/$1000.

Research and development expenditures were also used to evaluate KNOW, because the amount of money given to research directly affects innovation, and technological

advancements of corporations. For a sustainable corporation, the higher the value is the better. Data that was collected was made intrinsic by dividing by net sales ($/$). The minimum value for complete sustainability is 0.01$/$.

HEALTH

HEALTH
*Injury and illness rates (**INJURY**)*
*Lost workdays (**LOSTDAYS**)*

Table 3: Basic indicators used to evaluate the secondary indicator HEALTH

Injury rates were used to evaluate the health of employees, because employees hurt on the job cannot work efficiently, and other employees may become troubled by the incident. Employee productivity would increase if this value were minimized, and therefore for this basic indicator lower is better. Data collected on injury rates were listed per 100 employees (injury/100 employees). The maximum value for complete sustainability is 0.36 injuries/100 employees, and the minimum value for sustainability is 1.08 injuries/100 employees.

Lost workdays, were also used to evaluate HEALTH, and are a consequence of injury and illness rates. If an employee is unable to attend work, productivity of the corporation decreases when no one can replace the employee, or net revenue decreases if a replacement is found, since both employees still need to be paid. Thus, the lower the value for this indicator is the better. Data collected on lost work days were also listed per 100 employees (lost days/100 employees). The maximum value for complete sustainability is 0.11 lost days/100 employees, and the minimum value for sustainability is 0.42 lost days/100 employees.

POLIC

POLIC
*Noncompliance with national environmental laws/regulations (**NONENVIRO**)*
*Noncompliance with national labor laws/regulations (**NONLABOR**)*
*Fines Paid due to environmental noncompliance (**ENVIROFINES**)*
*Fines Paid due to labor noncompliance (**LABORFINES**)*

Table 4: Basic indicators used to evaluate the secondary indicator POLIC

Noncompliance, as it pertains to environmental laws and regulations, was used to evaluate POLIC because this may lead to a corporation having to shut down a plant. Multiple violations against environmental laws and regulations must be resolved, which could mean, for example, money spent changing a process so that it is environmentally friendly. Also, the public perception of the corporation may decline with increasing environmental violations. Clearly, the lower the value is the better. The maximum value for complete sustainability is 4 violations, and the minimum value for sustainability is 78 violations.

In addition to the number of environmental violations, the amount of fines paid for the violations were also used to evaluate POLIC. This data is important, since it shows the seriousness of each violation by how much the corporation had to pay for it. Lower is better for this indicator. The maximum value for complete sustainability is $2613, and the minimum value for sustainability is $100,000.

Noncompliance, as it pertains to labor laws and regulations, is also used to evaluate POLIC, for similar reasons to environmental laws and regulations. With an increase in violations, corporations may need to replace or retrofit equipment, change processes, etc. Such changes take time and money, and therefore decrease sustainability. Perception is also a concern, but of the employees, who may be unhappy with dangerous conditions, and thus less productive.

Future employees may also be deterred from working at a certain corporation with numerous health violations. Lower is better for this indicator. The maximum value for complete sustainability is 2 violations, and the minimum value for sustainability is 10 violations.

As with fines paid for environmental violations, fines paid for labor violations also demonstrate the extent of the violation, by putting a monetary value on it. Once again, lower is better for this indicator. The maximum value for complete sustainability is $300, and the minimum value for sustainability is $4,940.

WATER

WATER
*Total water use (**WATERUSE**)*
*Wastewater emissions (**WATEREMISS**)*

Table 5: Basic indicators used to evaluate the secondary indicator WATER

Total water use was used as a basic indicator for WATER. The amount of water used for production directly affects the environment. Water is necessary for most processes, but corporations can reduce the amount of water they use by treating and recycling water through their processes. Thus water use is better when low. The intrinsic values for the data collected were calculated by dividing water use by amount of waste generated (meters^3/ton). The maximum value for complete sustainability is 42.81 m^3/ton, and the minimum value for sustainability is 107.05 m^3/ton.

Wastewater emissions are an unavoidable part of many chemical processes, and were therefore used to evaluate WATER as well. Like water usage, wastewater emissions directly affect the environment, in a negative way. Wastewater emissions are therefore better when

low. No data could be found for this basic indicator, so the average linguistic value of total water use was used for calculations.

LAND

LAND
*Solid and liquid waste generation (**WASTEGEN**)*
*Amount of solid and liquid waste treated/recycled (**RECYCWASTE**)*

Table 6: Basic indicators used to evaluate secondary indicator LAND

Solid and liquid waste generation was used to evaluate LAND, because both directly affect the environment. Corporations generate a large amount of waste from their chemical processes, packaging, etc., and this waste ends up in landfills. Therefore, the less waste generated the better. To make the data collected intrinsic, the amount of waste generated was divided by the amount of waste generated (ton/ton). The maximum value for complete sustainability 36.73 ton/ton, and the minimum value for sustainability is 4940 ton/ton.

The amount of solid and liquid waste treated/recycled is related to generation, but has a positive effect on the environment. This basic indicator is important, in conjunction with generation, because it demonstrates by how much the corporation reduces their waste. The corporation's public perception may be better, because of their efforts to eliminate waste. This basic indicator is better when high, and data was collected in units of percentage. The minimum value for complete sustainability is 60%.

AIR

AIR
*Greenhouse gas emissions (production and product use/disposal) (**GHG**)*
*NOx, SOx, or CO emissions &VOC (**AIREMISS**)*
*Total energy use (**ENERGYUSE**)*

Table 7: Basic indicators used to evaluate secondary indicator AIR

Greenhouse gas emissions were used to evaluate AIR, since these emissions have a negative impact on the atmosphere. These gases eventually cause the greenhouse effect, where radiation is absorbed by the gases and re-radiated to the surface of the earth. This indicator is better when low. Intrinsic values were calculated by dividing emissions by the amount of waste generated (ton/ton). The maximum value for complete sustainability is 1.87 ton/ton, and the minimum value for sustainability is 4.15 ton/ton.

Nitrogen oxides, sulfur oxides, carbon monoxide, and volatile organic compound emissions were also used to evaluate air because they negatively affect the environment. These emissions may cause acid rain, ground-level ozone, smog, global warming, as well as health problems to humans and animals. This indicator is therefore better when minimized. The data collected on these emissions were made intrinsic by dividing tons of emissions by the amount of waste generated (ton/ton). The maximum value for complete sustainability is 0.014 ton/ton, and the minimum value for sustainability is 0.031 ton/ton.

Total energy use was used to evaluate AIR as well, because it indirectly affects the sustainability of air. The burning of fossil fuels is the primary source of energy, and therefore the more energy used, the more fossil fuels being depleted. Fossil fuels produce an excess of carbon dioxide, in which the environment cannot absorb, contributing to the greenhouse gas affect. The lower the energy used in production, therefore, the better. Data collected for energy usage was made intrinsic by dividing by the amount of waste generated (GJ/ton). The maximum value for complete sustainability is 60 GJ/ton, and the minimum value for sustainability is 100 GJ/ton.

Normalized and Fuzzy Values of Basic Indicators

The fuzzy values of all the basic indicators were calculated by first normalizing the data, and then using a membership function to assign fuzzy values. All calculations were done in Excel, unless otherwise noted. A sample calculation for one basic indicator, for every secondary indicator, is presented.

WEALTH

For secondary indicator WEALTH, NETSALES data was collected from corporation websites in which their SEC filings were listed. This data was also found on CNN's money website, and Yahoo's finance website. Since there are over 100 companies in the household and personal products industry, the financial "leaders" and "laggers," as denoted on Yahoo's finance website, were used to find normalization targets. This data is given in Table 8. The average value of the data was used as the minimum value for complete sustainability, which was rounded to $330,000 per employee.

	LEADER	LAGGERS			
	Unilever	**Female Health Company**	**CCA Industries**	**Creightons**	**United Guardian**
Net sales (millions)	$153,421 (average of 2006-2010 data)	$25 (average 2008-2010 data)	$55 (average of 2009-2010 data)	$14 (average of 2007-2010 data)	$12 (average of 2007-2009 data)
Employees	15,000	48	140	150	35
Net Sales/ Employee	$12,020,000	$425,000	$378,571	$98,000	$405,714

Table 8: Data collected from household and personal products industry's leaders and laggers to normalize NETSALES

Data was also collected from Proctor and Gamble's competitors, as denoted on CNN's Fortune 500 lists (Table 9). These values were used in conjunction with leaders and laggers values when

confirming that the normalization function was appropriate for this industry. Finally, data was collected for Proctor and Gamble's annual sustainability reports for the past 10 years.

	Avon	Colgate Palmolive	Estee Lauder Inc.
Net sales (millions)	$10,863 (2009)	$15,564 (2009)	$7,796 (2009)
Employees	41,000	38,100	31,300
Net Sales/ Employee	$264,946	$408,504	$249,067

Table 9: Data collected from P&G competitors to normalize NETSALES

	Proctor and Gamble										
Year (20-XX)	**00**	**01**	**02**	**03**	**04**	**05**	**06**	**07**	**08**	**09**	**10**
Net sales (billions)	$40	$39	$40	$43	$51	$57	$68	$77	$84	$79	$79
Employees	ND	ND	ND	ND	ND	107,000	136,000	135,000	135,000	132,000	127,000
Net Sales/ Employee	ND	ND	ND	ND	ND	$530,280	$501,618	$566,667	$618,519	$598,705	$621,559

Table 10: NETSALES data collected on Proctor and Gamble (ND denotes no data)

The normalization function is:

(1)

where z is the "smoothed" value (in this assessment, the average value), and x is the normalized value. Using this function, Proctor and Gamble's normalized value for NETSALES is 1.00 $/employee.

The membership function used to compute fuzzy values for all basic indicators is:

(2)

The fuzzy value for NETSALES is STRONG(1.0) . Crisp values of all indicators are calculated by the following equation:

(3)

where peak value is the value at which each linguistic value is at a maximum. According to equation (2), the peak values of WEAK, MEDIUM, AND STRONG, and 0, 0.7, and 1 respectively. Using the above equation, the crisp value for NETSALES was calculated to be 1.0.

KNOW

For secondary indicator KNOW, R&D data was collected from annual reports and sustainability reports posted on each corporation's website (Tables 11&12). The average value over all corporations listed in Table 11 is 0.1 $/$, and was used as the minimum value for maximum sustainability.

	Female Health Company	**CCA Industries**	**Avon**	**Colgate Palmolive**	**Estee Lauder Inc.**
R&D expenditures	$130,000 (average of 2008-2010 data)	$574,000 (average of 2008-2010 data)	$72,600,000 (2009)	$256,333,333 (average of 2007-2009 data)	$79,500,000 (2009)
R&D expenditures / Net sales	0.01	0.01	0.01	0.02	0.01

Table 11: Data collected from a variety of household and personal products corporations to normaliize R&D

	Proctor and Gamble										
Year (20-XX)	**00**	**01**	**02**	**03**	**04**	**05**	**06**	**07**	**08**	**09**	**10**
R&D expenditures (billions)	$1.7	$1.7	$1.7	$1.5	$1.8	$1.8	$1.8	$1.8	$2.0	$2.0	$2.0

R&D expenditures / Net sales	0.04	0.04	0.04	0.03	0.04	0.03	0.03	0.02	0.02	0.03	0.03

Table 12: R&D data collected on Proctor and Gamble

Proctor and Gamble's values were smoothed and entered into the following normalization function:

—

(4)

The normalized value for R&D is 1.00$/$. Using the membership function (2), its' fuzzy value is calculated to be STRONG(1.0). Its' crisp value was calculated to be 1.0.

HEALTH

For secondary indicator HEALTH, LOSTDAYS data was collected from Proctor and Gamble, and their competitors, as listed in Tables 13 and 14.

	Avon										**Colgate Palmolive**	**Estee Lauder Inc.**
Year (20-XX)	**00**	**01**	**02**	**03**	**04**	**05**	**06**	**07**	**08**	**09**	**09**	**09**
Lost days / 100 employees	0.87	0.73	0.4	0.34	0.24	0.19	0.23	0.19	0.12	0.11	0.76	0.15

Table 13: Data collected from a variety of household and personal products corporations to normaliize LOSTDAYS

	Proctor and Gamble										
Year (20-XX)	**00**	**01**	**02**	**03**	**04**	**05**	**06**	**07**	**08**	**09**	**10**
Lost days / 100 employees	0.40	0.24	0.35	0.22	0.27	0.17	0.16	0.26	0.24	0.15	0.22

Table 14: LOSTDAYS data collected on Proctor and Gamble

This data was found in annual and sustainability reports posted on each corporation's website. The lowest value, 0.11 lost days/ 100 employees, of the data was used as the maximum value for complete sustainability. The average value, 0.42 lost days/ 100 employees, of the data in Table 13 was used as the minimum value for sustainability. The normalization function is:

— — **(5)**

The normalized value of LOSTDAYS for P&G is 0.57 lost days/ 100 employees. Its' fuzzy value using the membership function (2) is WEAK(0.19) and MEDIUM(0.81). Using equation (3), the crisp value of LOSTDAYS was calculated to be 0.57.

POLIC

For secondary indicator POLIC, NONENVIRO data was collected from annual/sustainability reports on each corporations website (Table 15 & 16).

	Avon							**Colgate Palmolive**									
Year (20-XX)	**03**	**04**	**05**	**06**	**07**	**08**	**09**	**00**	**01**	**02**	**03**	**04**	**05**	**06**	**07**	**08**	**09**
Environmental Violations	1	4	7	1	3	1	0	2	7	5	6	5	3	0	8	8	7

Table 15: Data collected from household and personal products corporations to normaliize NONENVIRO

	Proctor and Gamble										
Year (20-XX)	**00**	**01**	**02**	**03**	**04**	**05**	**06**	**07**	**08**	**09**	**10**
Environmental Violations	36	61	42	67	64	78	45	36	74	26	36

Table 16: NONENVIRO data collected on Proctor and Gamble

The average value, 4 violations, of the data in Table 15 was used as the maximum value for complete sustainability. The largest value of all the data, 78 violations, was used as the minimum value for sustainability. The normalization is:

— — **(6)**

The normalized value for NONENVIRO is 0.36 violations, and the fuzzy value using (2) is WEAK(0.49) and MEDIUM(0.51). Using equation (3), the crisp value of NONENVIRO was calculated to be 0.36.

WATER

For secondary indicator WATER, data was collected on WATERUSE from annual/sustainability reports (Tables 17&18).

	Avon					
Year (20-XX)	**05**	**06**	**07**	**08**	**09**	**10**
Total water use (m^3)	2,081,976	2,119,831	2,063,049	2,063,049	1,816,998	1,854,852
Waste generated (tons)	38,555	40,823	49,895	53,524	49,895	47,627
Water use/waste generated (m^3/ton)	54.0	51.9	41.3	38.5	36.4	38.9

Table 17: Data collected from a household and personal products corporation to normaliize WATERUSE

	Proctor and Gamble										
Year (20-XX)	**00**	**01**	**02**	**03**	**04**	**05**	**06**	**07**	**08**	**09**	**10**
Total water use (millions m^3)	87	88.1	85	85	79	83	80	86	86	78	80

Waste generated (thousand)	879	910	798	794	817	831	873	983	935	871	1,048
Water use/waste generated (m^3/ton)	98.98	96.81	106.52	107.05	96.70	99.88	91.64	88.19	93.00	90.19	77.21

Table 18: WATERUSE data collected on Proctor and Gamble

The average value, 42.81 m^3/ton, of the data in Table 17 was used as the minimum value for sustainability. The maximum value, 107.05 m^3/ton, of the data in Table 18 was used as the maximum value for sustainability. The normalized function is:

(7)

The normalized value is 0.19 m^3/ton, and the fuzzy value is WEAK(0.73) and MEDIUM(0.27). Using equation (3), the crisp value of WATERUSE was calculated to be 0.19.

LAND

For secondary LAND, RECYCWASTE data was collected from annual/sustainability reports on each corporation's website (Tables 19 &20).

	Avon						**Estee Lauder**
Year (20-XX)	**04**	**05**	**06**	**07**	**08**	**09**	**07**
Amount of solid and liquid waste treated/recycled	52%	56%	58%	57%	65%	71%	56%

Table 19: Data collected from household and personal products corporations to normaliize RECYCWASTE

	Proctor and Gamble										
Year (20-XX)	**00**	**01**	**02**	**03**	**04**	**05**	**06**	**07**	**08**	**09**	**10**
Amount of solid and liquid waste treated/recycled	55%	51%	54%	52%	56%	58%	60%	55%	59%	66%	63%

Table 20: RECYCWASTE data collected on Proctor and Gamble

The average value, 60%, of the data in Table 19 was used as the maximum value for complete sustainability. The normalization function is:

(8)

The normalized value is 0.95, and the fuzzy value is MEDIUM(0.16) and STRONG(0.84). Using equation (3), the crisp value of RECYCWASTE was calculated to be 0.95.

AIR

For secondary indicator AIR, GHG data was collected from the annual/sustainability reports on each corporation's website (Table 21&22).

	Avon						
Year (20-XX)	**02**	**04**	**05**	**06**	**07**	**08**	**09**
Greenhouse gas emissions (production and product use/disposal) in tons	99,900	105,089	108,937	120,579	116,002	118,197	100,224
Greenhouse gas emissions (production and product use/disposal) per ton of waste	ND	ND	3.13	2.84	2.37	1.87	2.02

Table 21: Data collected from a household and personal products corporation to normaliize GHG

	Proctor and Gamble										
Year (20-XX)	**00**	**01**	**02**	**03**	**04**	**05**	**06**	**07**	**08**	**09**	**10**
Greenhouse gas emissions (production and product use/disposal) in millions of tons	ND	3.21	3.31	3.12	2.94	3.28	2.89	2.88	2.78	2.63	2.8
Greenhouse gas emissions (production and product	ND	3.53	4.15	3.93	3.59	3.95	3.31	2.93	2.98	3.01	2.67

use/disposal) per ton of waste											

Table 22: GHG data collected on Proctor and Gamble

The lowest value of the data in Table 21, 1.87 ton/ton, was used as the minimum value for complete sustainability of GHG. The highest value of the data in Table 22, 4.15 ton/ton, was used as the maximum value of sustainability for GHG. The normalized function is:

— — **(9)**

The normalized value of GHG is 0.46 ton/ton, and the fuzzy value is WEAK(0.34) and MEDIUM(0.66). Using equation (3), the crisp value of GHG was calculated to be 0.46.

Fuzzy and Crisp Values of Secondary Indicators

The fuzzy and crisp values of the secondary indicators were calculated by first generating rule bases in MATLAB. General rule bases from Phillis and Kouikoglou were used in most cases, unless otherwise stated.

WEALTH

To calculate the fuzzy value of wealth, a rule base is needed. All the possible combinations of WEAK (W), MEDIUM (M) and STRONG (M), for the basic indicators of WEALTH (NETSALES, COMSHARE, MARCAP, and GENOP) were generated (Table 23). Weak was assigned a value of 0, medium a value of 1, and strong a value of 2. For all the combination of inputs, the sum of these values was calculated, and the linguistic value of WEALTH was determined by:

(10)

Where VB is VERYBAD, B is BAD, A is AVERAGE, G is GOOD, and VG is VERYGOOD. The basic indicators WEALTH all had a fuzzy value of STRONG, so only one rule fires. According to the rule base, WEALTH was assigned a value of VERYGOOD.

If NETSALES is	if COMSHARE is	if MARCAP is	if GENOP is	then WEALTH is
W	W	W	W	VB
W	W	W	M	VB
W	W	W	S	VB
W	W	M	W	VB
W	W	M	M	VB
W	W	M	S	B
W	W	S	W	VB

W	W	S	M	B
W	W	S	S	A
W	M	W	W	VB
W	M	W	M	VB
W	M	W	S	B
W	M	M	W	VB
W	M	M	M	B
W	M	M	S	A
W	M	S	W	B
W	M	S	M	A
W	M	S	S	G
W	S	W	W	VB
W	S	W	M	B
W	S	W	S	A
W	S	M	W	B
W	S	M	M	A
W	S	M	S	G
W	S	S	W	A
W	S	S	M	G
W	S	S	S	VG
M	W	W	W	VB
M	W	W	M	VB
M	W	W	S	B
M	W	M	W	VB
M	W	M	M	B
M	W	M	S	A
M	W	S	W	B
M	W	S	M	A
M	W	S	S	G
M	M	W	W	VB
M	M	W	M	B
M	M	W	S	A
M	M	M	W	B
M	M	M	M	A
M	M	M	S	G
M	M	S	W	A
M	M	S	M	G
M	M	S	S	VG
M	S	W	W	B

M	S	W	M	A
M	S	W	S	G
M	S	M	W	A
M	S	M	M	G
M	S	M	S	VG
M	S	S	W	G
M	S	S	M	VG
M	S	S	S	VG
S	W	W	W	VB
S	W	W	M	B
S	W	W	S	A
S	W	M	W	B
S	W	M	M	A
S	W	M	S	G
S	W	S	W	A
S	W	S	M	G
S	W	S	S	VG
S	M	W	W	B
S	M	W	M	A
S	M	W	S	G
S	M	M	W	A
S	M	M	M	G
S	M	M	S	VG
S	M	S	W	G
S	M	S	M	VG
S	M	S	S	VG
S	S	W	W	A
S	S	W	M	G
S	S	W	S	VG
S	S	M	W	G
S	S	M	M	VG
S	S	M	S	VG
S	S	S	W	VG
S	S	S	M	VG
S	S	S	S	VG

Table 23: Rule base for WEALTH

The degree of belonging of WEALTH to VERYGOOD was found using the Larsen implication, which multiplies the membership grades of the basic indicators. All the membership grades had a value of 1, and therefore the degree of belonging is 1.0.

The crisp value was calculated using equation (3), and the following membership function for all secondary indicators:

(11)

The crisp value in this case is 1.0.

KNOW

The linguistic values of KNOW were determined by:

(12)

The rule base used is therefore:

KNOW RULE BASE		
if PHILANTHROP is	**if R&D is**	**then POLIC is**
W	W	VB
W	M	B
W	S	A
M	M	A
M	W	B
M	S	G
S	S	VG
S	W	A
S	M	G

Table 24: Rule base for KNOW

The fuzzy value of KNOW was calculated to be VG (1.0), and the crisp value of know was calculated to be 1.0

HEALTH

The linguistic values of HEALTH were determined by:

(13)

The rule base is therefore:

HEALTH RULE BASE		
if INJURY is	**if LOST DAYS is**	**then HEALTH is**
W	W	VB
W	M	B
W	S	A
M	M	A
M	W	B
M	S	G
S	S	VG
S	W	A
S	M	G

Table 25: Rule base for HEALTH

The fuzzy value of HEALTH was calculated to be G(0.12), A(0.03), A(0.69), and B(0.16). The crisp value of KNOW was calculated to be 0.49.

POLIC

The linguistic values of KNOW were determined by:

(14)

The rule base used is therefore:

if NONENVRIO is	if ENVIROFINES is	if NONLABOR is	if LABORFINES is	then POLIC is
W	W	W	W	VB
W	W	W	M	VB
W	W	W	S	VB
W	W	M	W	VB
W	W	M	M	VB
W	W	M	S	B
W	W	S	W	VB
W	W	S	M	B
W	W	S	S	A
W	M	W	W	VB
W	M	W	M	VB
W	M	W	S	B
W	M	M	W	VB
W	M	M	M	B
W	M	M	S	A
W	M	S	W	B
W	M	S	M	A
W	M	S	S	G
W	S	W	W	VB
W	S	W	M	B
W	S	W	S	A

W	S	M	W	B
W	S	M	M	A
W	S	M	S	G
W	S	S	W	A
W	S	S	M	G
W	S	S	S	VG
M	W	W	W	VB
M	W	W	M	VB
M	W	W	S	B
M	W	M	W	VB
M	W	M	M	B
M	W	M	S	A
M	W	S	W	B
M	W	S	M	A
M	W	S	S	G
M	M	W	W	VB
M	M	W	M	B
M	M	W	S	A
M	M	M	W	B
M	M	M	M	A
M	M	M	S	G
M	M	S	W	A
M	M	S	M	G
M	M	S	S	VG
M	S	W	W	B
M	S	W	M	A
M	S	W	S	G
M	S	M	W	A
M	S	M	M	G
M	S	M	S	VG
M	S	S	W	G
M	S	S	M	VG
M	S	S	S	VG
S	W	W	W	VB
S	W	W	M	B
S	W	W	S	A
S	W	M	W	B
S	W	M	M	A

S	W	M	S	G
S	W	S	W	A
S	W	S	M	G
S	W	S	S	VG
S	M	W	W	B
S	M	W	M	A
S	M	W	S	G
S	M	M	W	A
S	M	M	M	G
S	M	M	S	VG
S	M	S	W	G
S	M	S	M	VG
S	M	S	S	VG
S	S	W	W	A
S	S	W	M	G
S	S	W	S	VG
S	S	M	W	G
S	S	M	M	VG
S	S	M	S	VG
S	S	S	W	VG
S	S	S	M	VG
S	S	S	S	VG
W	W	W	W	VB
W	W	W	M	VB

Table 26: Rule base for POLIC

The fuzzy value for POLIC is listed in Table 27. The crisp value was calculated to be .03.

Fuzzy Value of POLIC	
VB	0.107546
VB	0.075356
VB	0.173167
VB	0.121335
VB	0.001888
VB	0.001323
VB	0.00304
B	0.00213
VB	0.11384
VB	0.079766

VB	0.183301
B	0.128437
VB	0.001999
B	0.0014
B	0.003218
A	0.002255

Table 27: Calculated fuzzy value of POLIC

WATER

The fuzzy value of WATER was given a fuzzy value based on the KNOW rule base, since it had only one basic indicator that had data. The basic indicator, WATEREMISS, was calculated to be W(1.0) from the average value of the linguistic values of WATEREMISS. The fuzzy value of WATER is VB(.73) and B(.27). The crisp value was calculated to be .07.

LAND

The linguistic values of KNOW were determined by:

The rule base used is therefore:

LAND RULE BASE		
if WASTEGEN is	**if RECYCWASTE is**	**then LAND is**
W	W	VB
W	M	B
W	S	A
M	M	A
M	W	B
M	S	G
S	S	VG
S	W	A
S	M	G

Table 28: Rule base for LAND

The fuzzy value of LAND was calculated to be G (0.13), G (0.41), G (0.08), and G (0.25). The crisp value of LAND was calculated to be 0.75.

AIR

The linguistic values of KNOW were determined by:

It should be noted that since the corporations had generally low values for AIR, the rule base was adjusted to be slightly more optimistic.

The rule base used is therefore:

AIR RULE BASE			
if GHG is	**if AIREMISS is**	**if ENERGYUSE is**	**then AIR is**
W	W	W	VB
W	W	M	VB
W	W	S	B
W	M	W	VB
W	M	M	B
W	M	S	A
W	S	W	B
W	S	M	A
W	S	S	A
M	W	W	VB
M	W	M	B
M	W	S	A
M	M	W	B
M	M	M	A
M	M	S	A
M	S	W	A
M	S	M	A

M	S	S	G
S	W	W	B
S	W	M	A
S	W	S	A
S	M	W	A
S	M	M	A
S	M	S	G
S	S	W	A
S	S	M	G
S	S	S	VG

Table 29: Rule base for AIR

The fuzzy value for AIR is listed in Table 30. The crisp value is 0.33.

Fuzzy value of AIR	
VB	0.01
VB	0.05
VB	0.05
B	0.23
VB	0.02
B	0.10
B	0.10
A	0.44

Table 30: Calculated fuzzy value of AIR

Fuzzy and Crisp Values of Primary Indicators

The fuzzy and crisp values of primary indicators HUMS AND ECOS were calculated using the crisp values of the secondary indicators. The crisp values were first put into membership function (11), repeated below, to attain linguistic values of each secondary indicator:

The linguistic value and membership grades are listed in Table 31.

HUMS	
WEALTH	VG(1.0)
KNOW	VG(1.)
HEALTH	B(0.04), A(0.96)
POLIC	VB(0.88), B(0.12)
ECOS	
WATER	VB(0.72), B(0.28)
LAND	G(1.0)
AIR	B(0.68), A(0.32)

Table 31: Fuzzified values of crisp values of secondary indicators

The rule bases that fire for these indicators are listed in Tables 32 and 33. VERYBAD, BAD, AVERAGE, GOOD, and VERYGOOD were assigned a value of 0,1,2,3, and 4 respectively. The sum of each linguistic value was calculated for each rule, and HUMS and ECOS were assigned a linguistic value based upon the following:

The Larsen implication was used again to calculate the degree of belonging (the product of the membership grades of the secondary indicators).

HUMS RULE BASE					
if WEALTH is	**if KNOW is**	**if HEALTH is**	**if POLIC is**	**then HUMS is**	**Degree of belonging**
VG	VG	B	VB	G	0.04
VG	VG	B	B	G	0.00
VG	VG	A	VB	A	0.84
VG	VG	A	B	G	0.12

Table 32: Rules base for HUMS based on equation (17)

ECOS RULE BASE				
if WATER is	**if LAND is**	**if AIR is**	**then ECOS is**	**Degree of Belonging**
VB	G	B	B	0.49
VB	G	A	A	0.23
B	G	B	A	0.19
B	G	A	B	0.09

Table 33: Rules base for ECOS based on equation (17)

Finally, the crisp values were calculated using equation (3). HUMS was calculated to be 0.54, and ECOS 0.40.

OSUS

The overall sustainability was calculated from ECOS and HUMS, using a general rule base in (Kouikoglou 102). The crisp value is 0.29, and the fuzzy value is listed in Table 34.

Fuzzy Value of OSUS								
Linguistic values	**Degrees of Belonging**							
Intermediate	0.017	0.003	0.002	0.010	0.056	0.010	0.195	0.161
Fairly High	0.008	0.007	0.001	0.001	0.027	0.022		

Table 34: Fuzzy value of overall sustainability

The overall sustainability of Proctor and Gamble has a fuzzy value mainly towards the middle (intermediate) region. Their HUMS values were generally towards the "good" side, while their ECOS values were more "bad" to "average." Such values are expected of a large, Fortune 500 corporation, such as Proctor and Gamble, which produces a wide variety of products from chemical processes. The corporation is averaging higher values than most of their competitors, which tends to drive up all fuzzy and crisp values pertaining to WEALTH. Hence why the corporation's HUMS fuzzy value had so many GOOD linguistic values. Proctor and Gamble's size clearly helped HUMS, but consequently hurt ECOS. The number, and variety of products produced by Proctor and Gamble made their effects on the environment much greater than other corporations (even when normalized).

Recommendations for future work on assessing the sustainability of Proctor and Gamble include data collection from more household and personal products corporations, for a better choice of normalization targets, and calculation of rules bases. Specifically, more basic indicators should also be found for ECOS, since it is not easily apparent where the corporation stands (as opposed to HUMS). Overall, from this assessment, Proctor and Gamble is deemed fairly sustainable.

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