

# Sustainability Assessment of L'Oréal by Fuzzy Evaluation

THE COOPER UNION  
ChE447, Prof. Stevenson  
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Lucy Choi, Michelle Weng, Hengnan Ma

# Abstract

Using the SAFE (Sustainability Assessment by Fuzzy Evaluation; developed by Phillis et al.) model, the sustainability of L'Oréal, a cosmetics company based in France, was assessed. The particular model for the evaluation of L'Oréal (Figure 1) uses a total of 22 basic indicators that encompass a wide range of environmental, societal, and economic impacts in order to hierarchically assess and form more complete indicators until the overall sustainability is calculated.

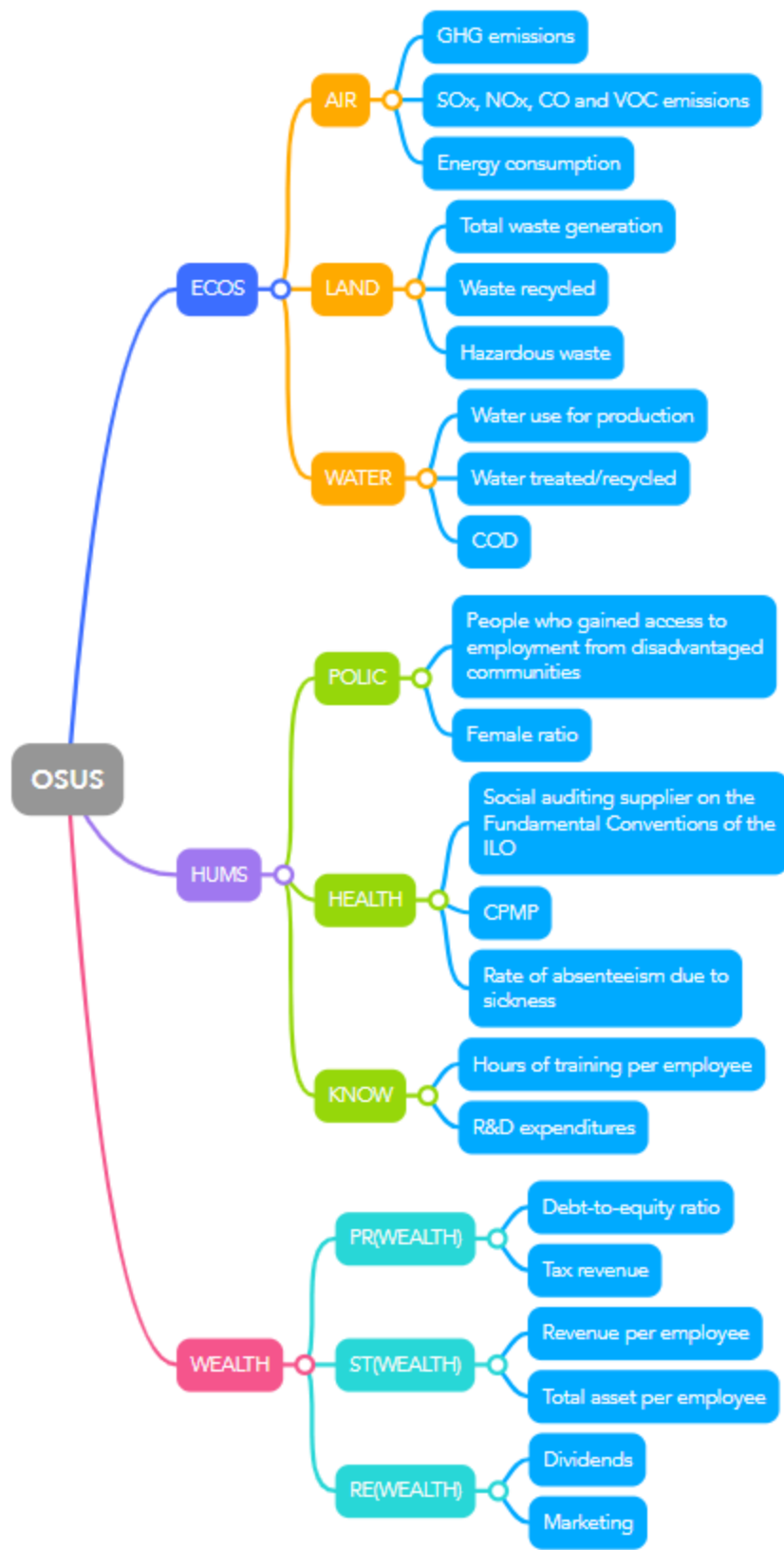


Figure 1. The SAFE model for L'Oréal

The overall sustainability (OSUS) in the SAFE model encompasses three components or primary indicators, namely, ecological sustainability (ECOS), human sustainability (HUMS), and wealth (WE). The ECOS consists of four secondary indicators: water quality (WATER), land integrity (LAND), air quality (AIR), and biodiversity (BIO, which is omitted for L'Oréal due to lack of data). The HUMS consists of three secondary indicators: political aspects (POLIC), health (HEALTH), and education (KNOW). The WEALTH consists of three secondary indicators: PR(WEALTH), ST(WEALTH), and RE(WEALTH), which indicate pressure, state, and response, respectively. The results indicate that L'Oréal's operations are most sustainable in their impact on air and PR(WEALTH), while they are least sustainable in their impact on water and health. The overall sustainability (OSUS) of L'Oréal was determined to be **0.451**, based on a [0,1] scale with 1 being fully sustainable. This suggests that L'Oréal is a moderately sustainable corporation. The results of the sensitivity analysis imply that decreasing the water use for production and COD release and increasing the percentage of people who gained access to employment from disadvantaged communities seems most urgent for improving their OSUS, whereas the change in tax revenue has a negligible impact on OSUS.

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# Introduction

In the ever-evolving landscape of the cosmetics industry marked by robust growth and competition, sustainability has risen to become a concern for both consumers and businesses. In 2022, the global cosmetics market was valued at 430 billion dollars and is on the path to growing to 580 billion by the year 2027, growing by a projected 6 percent per year.<sup>1</sup> The industry has proved itself resilient even during global economic crises and macroeconomic conditions produced by the lockdowns from COVID-19. Today, the beauty market encompasses skincare, fragrance, makeup, haircare, and many other categories.

Amidst this flourishing industry, it is no surprise that the industry is becoming more competitive. Independent brands that emerged from the past decade seek to scale their production and enter more markets. This large influx of competitors has promoted established brands and retailers to adapt to the evolving landscape of the beauty industry. Meanwhile, consumers are becoming increasingly affluent and open to trying new brands and products of all price points. Another large contributor to the growth of the cosmetics industry is the growth of the e-commerce industry. E-commerce in beauty now accounts for more than 20 percent of all sales and is expected to grow 12 percent annually between 2022-2027.<sup>2</sup> With the expansion of online giants like Amazon and Alibaba along with an increase in the adoption of social selling, physical stores are expected to continue to lose market share globally.

The consequence of this rapid expansion into the industry comes in the form of high resource consumption, increased waste generation, use of dangerous chemicals, and environmental concerns. Recognizing the need to address these issues, consumers and activists are calling for an increased shift in sustainable production. Companies are facing greater pressure to adopt ethical and eco-friendly changes, reduce their carbon footprint, and actively contribute to sustainability on all levels.

In addition to the environment, companies must take the well-being of their employees into account to foster a healthy workplace. This includes the amount companies spend on the knowledge of their employees, whether that's investments in research or the increased hours for training. In addition, factors like the overall health of the workforce in terms of the sickness rate, alongside the quality of products produced, are crucial factors as well as the diversity of the company.

The company in question, L'Oréal is a French multinational beauty and cosmetics company headquartered in Clichy, France. Established in 1909 by Eugene Schueller, it has since become one of the world's largest and most respected companies in the cosmetics industry. L'Oréal offers a large array of beauty and cosmetics products such as skincare, haircare, makeup, and fragrances. The company is known for its diverse and high-quality product line generating 29.9 billion euros (\$32 billion) in sales spanning 150 countries and employing 88000 employees.<sup>3</sup> The company's commitment to a more sustainable and responsible business model extends beyond its commercial success, as displayed by its transparent efforts toward a more sustainable business model.

Recognizing the challenges posed by the industry's growth, it becomes of vital importance for L'Oréal to undergo a comprehensive sustainability assessment. This report aims to voice the rationale for employing the SAFE model and outline its relevance in L'Oréal's commitment to sustainability.

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<sup>1</sup>The Beauty Market in 2023

<sup>2</sup>The Beauty Market in 2023

<sup>3</sup> L'Oréal Group

# Model Description

## Selection of Basic Indicators

### AIR

- 1) *Greenhouse gas (GHG) emissions* (metric tons CO<sub>2</sub> equivalent emitted per million dollars of annual net sales) measure a company's contribution to climate change through its carbon footprint relative to its economic output. Reduced GHG emissions signify greater sustainability, lowering the company's vulnerability to environmental regulations, carbon taxes, and ecological harm worldwide.

The target value is set at 0.623, which is L'Oréal's lowest value within the investigated time period. The threshold of the undesirable value is set at 9.80, which is the maximum of all investigated competitor companies (Unilever) excluding P&G because the value was too large.

- 2) *SOx and VOC emissions* (metric tons per million dollars of annual net sales) measure the direct impact of a company's industrial processes on air quality. These emissions contribute to air pollution and can harm human health and the environment. Lower emissions signify reduced air pollution and a more sustainable production process, benefiting the environment and public health.

The target value for the combined air emissions is set at 0.00102, which is 25% of L'Oréal's current value. The least desirable value is set at 0.0998, which is the maximum value in the investigated competitor companies (P&G).

- 3) *Energy consumption* (MWh per million dollars of annual net sales) quantifies a company's energy efficiency and environmental impact. High energy consumption contributes to greenhouse gas emissions and depletes natural resources. Measuring energy consumption allows us to assess their energy efficiency and identify opportunities for reducing energy consumption, which is critical for both environmental sustainability and cost savings.

The target value for energy consumption is set at 23.4, which corresponds to L'Oréal's all-time lowest value. The undesirable value is set at 117, which is the average of the two investigated companies (ELC and P&G).

### LAND

- 1) *Solid and liquid waste generation* (tons per million dollars of annual net sales) is a key indicator as it reflects a company's impact on land resources. Corporations generate a large amount of waste from their manufacturing process and packaging, where it gets dumped into landfills rather than reused or recycled. Excessive waste generation can lead to land contamination, habitat destruction, and environmental degradation. A lower amount of waste generated is better for the environment due to less pollution of the land and a greater amount of land available to the ecosystem for other purposes.

The target value is set at 2.10, which is L'Oréal's lowest value within the investigated period. The undesirable value is set at 8.47, which is the maximum of all invested companies (P&G).

- 2) *Solid and liquid waste recycled* (percent of total) assess a company's commitment to recycling and reducing its waste footprint. The more waste is reused or recycled, the more sustainable it is. A higher percentage of waste recycled indicates a company's effort to minimize its impact on land resources and reduce the burden on landfills.

The target value is set at 99.4, which is the maximum of all investigated companies. The least desirable value is set at 90.9, which is equal to L'Oréal's lowest value within the investigated period.

- 3) *Hazardous waste generated* (metric tons per million dollars of annual net sales) by the company harms the environment because that waste must be treated or dumped. This indicator is crucial for assessing the potential environmental and health risks associated with a company's operations. The less hazardous waste the company produces, the better it is for the environment.

The target value is set at 0.0810, which corresponds to the minimum of all investigated companies. The undesirable value is set at 0.847, which is the maximum of all investigated companies.

## WATER

- 1) *Water use for production* (m<sup>3</sup> per ton of bulk product) is the volume of freshwater used by the company's plants and distribution centers and is a relevant indicator because clean freshwater is an essential component in industrial processes. The measure can be used to create water sustainability targets towards minimizing the water footprint of formulas and industrial processes. This in turn helps place less stress on the watersheds and communities they serve and operate in.

The target value is set at 1.51, which corresponds to the volume that is needed in order to achieve the company's 2030 declaration to reduce water use by 30% from the 2019 measurement. The undesirable value is set at 4.50, which is the maximum of all investigated companies.

- 2) *Water treatment/recycling* (percent of total site locations) assesses the company's effort to recycle, thereby reducing its water footprint at production sites. A higher percentage of water recycling indicates the company's dedication to innovative water management practices and the sustainable use of water in the areas it operates.

The target value is set at 100, which corresponds to the company's 2030 declaration to have 100% of the water used in industrial processes recycled and reused in a loop. To do this, they are innovating their current factories to acquire the 'waterloop factory' title. The undesirable value is set at 12.0, which is L'Oréal's lowest percentage within the investigated period.

- 3) *COD* (kg per ton product) stands for Chemical Oxygen Demand, providing insights into the quality of wastewater released by the company's factories. This indicator is crucial for assessing potential environmental risks associated with high COD levels, including their impact on aquatic life forms. Elevated COD levels signify a greater amount of chemically oxidizable organic material in the wastewater, and if not treated well, can reduce dissolved oxygen (DO) levels in



aquatic ecosystems. Thus, COD is a standard water treatment test for identifying the presence of organic pollutants and assessing the effectiveness of the company's water treatment methods.

The target value is set at 1.00, which corresponds to the company's internal standard for the quality of industrial wastewater, which they hope to reach in all of their factories by 2030. The undesirable value is set at 18.4, which is L'Oréal's highest value within the investigated period.

## POLIC

- 1) *Access to employment from disadvantaged communities* (% of total employees) offers insights into a company's commitment to improving the nation by reducing unemployment. A strong dedication to broadening access to employment plays a pivotal role in creating more opportunities for job seekers from socially or financially disadvantaged communities. This not only contributes to individual empowerment but also aligns with broader societal goals of fostering inclusivity and economic equity.

The undesirable value is set to 0.204, which is L'Oréal's lowest value within the investigated period. The target value is set at 1.18, which is L'Oréal's highest value within the investigated period.

- 2) *Female ratio* (percent of females in strategic positions) assesses the balance of women and men within the company's leadership. It plays a pivotal role in ensuring diversity, equal opportunities, and a well-rounded perspective at the highest levels of leadership.

Female employee ratio should not be too low or too high. The minimum value for sustainability is set at  $v_c = 29\%$  because this percentage is the average in the industry with hopes of improvement<sup>4</sup>. Full sustainability is achieved in the range of 49% to 50%, when half of all employees are female. Sustainability is zero at 100%, when all employees are female.

## WEALTH

### PR(WEALTH)

- 1) *The debt-to-equity ratio* is a financial metric that measures the ratio of a company's debt over its equity. It is used to assess the amount of leverage a company holds. Debt is not necessarily a bad indicator of a company's health, in fact, leveraging debt can be extremely beneficial to the growth of a company. However, having a high debt-to-equity ratio puts the company at a higher risk of defaulting on its loans in the event of sudden interest hikes.

The target ratio of 0 suggests that a company is less financially leveraged, which means they have a lower risk of financial problems and bankruptcy. This is also viewed favorably by both investors and lenders. An undesirable ratio is  $\geq 0.46$  since it indicates that a company does not have enough assets to pay off its debt. 0.46 is the maximum of all investigated competitors.

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<sup>4</sup><https://www.entrepreneur.com/growing-a-business/improving-gender-equality-in-the-beauty-industry/290938#:~:text=Though%20the%20beauty%20industry%20fares,the%20LedBetter%20Gender%20Equality%20Index.>

Companies in this position may struggle to meet their interest payment deadlines and their ability to find future investors may be limited compared to companies with a lower ratio.

- 2) *Tax revenue* (percent of annual sales) is a significant measure of the company's societal impact. It quantifies the company's contribution to society through mandatory tax payments to the government. Calculation of this indicator was carried out by finding the federal tax return and dividing it by the net sales. This indicator underscores the company's role in financing public services, infrastructure, and essential community needs, reflecting its broader social and economic influence.

Tax revenue shouldn't be too low or too high because if the tax revenue is too high, it might suggest that the company is shouldering an excessive burden in terms of taxes relative to its sales. On the other hand, if the tax revenue is too low, it could imply that the company is not contributing its fair share to society. The minimum and maximum value for full sustainability is 4.0 and 7.0, respectively. Meanwhile, zero tax and 100% tax are both undesirable because zero tax would mean that there is no support for the government's functions and 100% tax would mean the company makes no net profit.

#### ST(WEALTH)

- 3) *Net sales revenue per employee* (million \$ per year) tells us the economic output generated on average by each employee in the company. The sales revenue/employee can be a helpful indicator for assessing the efficiency of a company and if there is a need for internal restructuring. A higher revenue per employee can suggest that company workers are more productive and have access to better-paying jobs, leading to a better quality of life.

The target revenue per employee, 0.757, is the maximum of all investigated competitor companies, thereby representing the benchmark for the company's competitiveness. Conversely, an undesirable value is denoted by  $\leq 0.320$ , a threshold derived from L'Oréal's historical low. Such a value suggests stagnation or a lack of growth in terms of each employee's contribution to the company.

- 4) *Total Assets per employee* (€) can tell us the current economic status of a company. It is a metric that measures the complete accounting of everything a business owns and its combined value. Calculating these assets can help a company better understand its financial health and how much value it has. Companies can use this metric to plan and determine if they are able to pay their bills or how much they have for purposes such as expansion.

The undesirable is set at 0.399 which is the minimum of the 10-year time period. It is a value that L'Oréal should not approach as that would suggest a counterintuitive negative growth. A target value is 0.536 representing L'Oréal's maximum value within this period.

#### RE(WEALTH)

- 5) *Dividends* proposed to the annual general meeting (€) per million euros of sales reflect a company's economic health and its commitment to shareholder value. Dividends signify the

company's ability to generate profits and distribute them among its investors, providing a tangible measure of its economic viability. A higher dividend can be attractive to shareholders, while a lower yield may make the stock less competitive relative to the industry. Generally speaking, larger and matured companies tend to have higher dividend yields compared to new/smaller companies.

The minimum value for full sustainability, 0.0146, is L'Oréal's lowest value within the investigated period. The better value is 0.0270 since it is the company's highest value. Having a figure closer to this higher value is viewed favorably by both investors and lenders. Companies on the lower end may struggle to meet investor expectations and could face challenges in attracting and retaining shareholders. This may be indicative of financial difficulties or limitations in the company's profit-generation capacity.

- 6) *Marketing as a percentage of sales* lets the reader understand how much is spent on marketing for every dollar that is generated in sales. It is a useful metric to determine the current stance of a company. A lower marketing budget can indicate that a company is happy with its current position in the market or its market share while a high marketing budget shows that a company is in a period of unsustainable but rapid growth.

To ensure that L'Oreal is in a sustainable position, the minimum target for sustainability is 5%. Full sustainability starts at the industry standard for growth at 10 percent and ends at L'Oréal's minimum value. An unsustainable position is L'Oréal's maximum value for this metric at 32.8. Although this value is understandable based on the current cosmetics market, it is ultimately unsustainable to spend this amount of money purely on advertisement.

## HEALTH

- 1) *The number of complaints that a company receives per million products sold* is a metric for assessing customer satisfaction and the quality of products sold. A lower CPMP indicates that a company is delivering high-quality products and maintaining a strong customer relationship, while a higher CPMP may suggest potential issues with product quality, customer service, or both. Addressing CPMP is essential for companies to have a positive reputation, retain customers, and long term growth.

The target of 0 complaints per million products sold is the ideal value. The undesirable value of 52 is set as L'Oréal's maximum value within the time span.

- 2) *Social auditing suppliers on the Fundamental Conventions of the ILO* (audits/supplier\* year) measures the adherence of suppliers to key principles and rights at work. The ILO governing body has identified "fundamental" Conventions, covering subjects that are considered to be fundamental principles and rights at work. These conventions can include but are not limited to child labor, forced labor, health and safety, compliance with the laws relating to trade unions, non-discrimination, disciplinary practices, sexual harassment or a hostile working environment, due payment of wages/compensation and benefits, working time, and relations with subcontractors. Audits by independent unbiased third parties help businesses ensure that industry standards and other requirements are met. Issues can also be identified and resolved before they can become significant and affect the business' public image negatively.

The minimum value for full sustainability is represented by 2.15, the average of L'Oréal's values. The maximum value for full sustainability is 4, which is represented by a typical factory's number of audits. An undesirable value is 0 audits per year, but 16 is also too many audits because it increases the chances of audit fatigue, and the cost associated with conducting numerous audits can outweigh the benefits.

- 3) *The overall rate of absenteeism due to sickness* is calculated as  $C/(A+B)$ . Where A is the number of days effectively worked by all employees with contracts, including training days. B is the number of days of absence (sick leave, occupational diseases, maternity leave, accidents in the workplace, and/or travel-to-work accidents, or any other absence not provided for by contract). C is the number of days of sick leave (excluding occupational diseases, maternity leave, accidents in the workplace, and/or travel to work accidents). This is a great metric that indicates the general health and well-being of the workforce. Having a healthy workforce lowers this ratio and increases efficiency in the organization.

The target 2.15 was obtained from L'Oréal's minimum value within the investigated period. With an undesirable percentage of 2.67, which is the maximum of L'Oréal's value within the time span.

## KNOW

- 1) *Hours of training per employee* (hr per year) measure the impact of company training on new employees, indicating a commitment to onboarding and skill development. Moreover, it can also reflect the perception and experience of employees regarding the company's educational efforts. Enhancing employee training signifies not only the company's commitment to training but also the effectiveness of these programs in aligning with employee needs and expectations. This, in turn, contributes to higher productivity, fosters a positive company culture, and enhances employee satisfaction.

The hours of training per employee should not fall below a certain threshold. The minimum value for sustainability is set at 25.4 hours because this figure represents the company's lowest recorded value. A higher value would signify that the entire workforce is actively engaged in enhancing their skills. Full sustainability is achieved at 64 hours to align with the highest value observed among the researched competitors.

- 2) *R&D expenditures* (% of sales) reflect the company's investment in innovative research and development. R&D efforts extend beyond product improvement; they also contribute to the development of sustainable operations. These advancements can make the company more efficient, reduce costs, and minimize its environmental footprint, aligning with interests in business growth.

The more a company invests in R&D, the more it might benefit from the results or insights gained from the research. The minimum value for sustainability is set at 1.5% because this percentage is the lowest value recorded among the competitors. Full sustainability is set at 3.7% because this percentage is the highest value recorded by L'Oréal in the investigated time period.



## Normalization and Fuzzification of Basic Indicators

The 22 basic indicators explained above come in a variety of units of different scales, making it necessary to normalize the data on a 0-1 scale. We wanted values to become more comparable and to mitigate potential bias caused by indicators with larger numerical ranges. As such, the normalization method by linear interpolation was used to find the normalized values by defining desirable and undesirable values (Table 1).

Desirable and undesirable values were based on four sources: L'Oréal data collected within the certain timespan of 2012-2022, L'Oréal's 2030 corporate goals, cosmetics and beauty industry standards, and the 2022 data from three of L'Oréal's competitors. We collected data on Estée Lauder Companies, Procter & Gamble, and Unilever, when available.

Depending on the target set, there were three normalizations by linear interpolation methods to choose from. For example, GHG emissions per million dollars of annual net sales used the maximum value among the four companies in 2022 (See raw indicator data in Appendix 1). This value is set as the least desirable value,  $U$ . The same table shows L'Oréal's GHG emissions to be at the lowest in 2022. This value was set as the target,  $T$ . Emissions need to be at most equal to  $T$  to be sustainable. For this indicator, smaller is better so SB normalization was used, and the curve describing the calculation is shown in Figure 2.

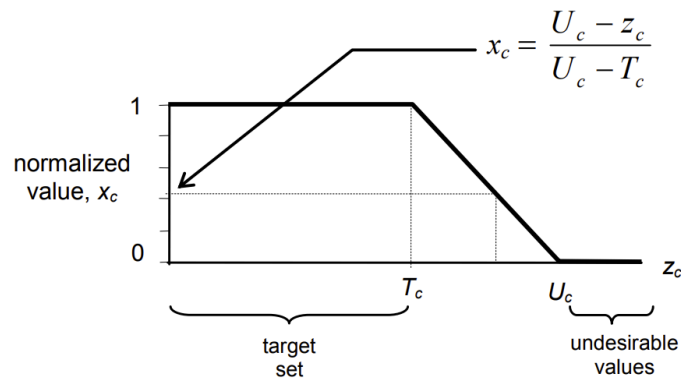


Figure 2. Normalization by linear interpolation for SB

The normalization curve for GHG emissions with  $U = 9.8$  and  $T = 0.62$  tons CO<sub>2</sub>-eq emitted per million dollars of annual net sales is shown below.

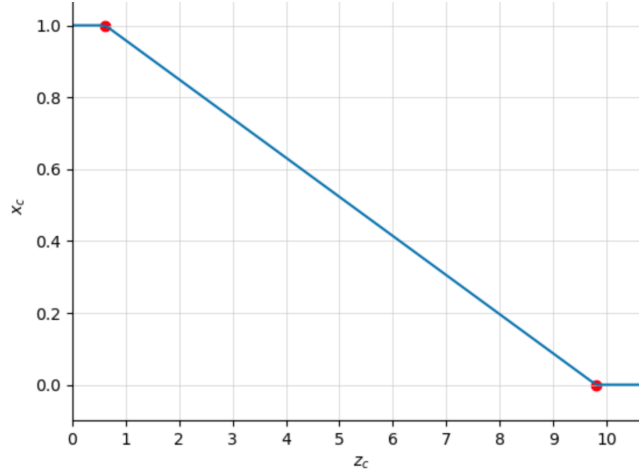


Figure 3. Normalization curve for GHG emissions

GHG emissions represent a metric that companies consistently endeavor to diminish in response to environmental regulations, and this ongoing commitment is notably discernible in Hanwha's historical data (refer to the Appendix raw data spanning from 2012 to 2022). In order to establish a representative value for the company, we computed the average of the most recent three years' data (2020-2022) for normalization. Subsequently, the computed average was normalized using the provided equation.

$$x_c = \frac{U_c - z_c}{U_c - T_c} = \frac{9.80 - 1.12}{9.80 - 0.623} = 0.946$$

The two other types of normalization, LB and NB, were chosen if larger is better or nominal is best (Figures 3 and 4). For the former, the interval  $[v_c, \tau_c]$  is chosen when an indicator must be at least equal to  $\tau$  to be fully sustainable. For the latter, an indicator must lie in  $[\tau_c, T_c]$  to be sustainable.

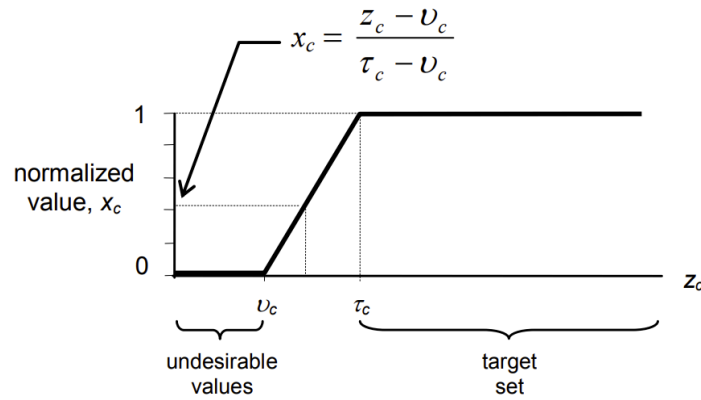


Figure 3. Normalization by linear interpolation for LB

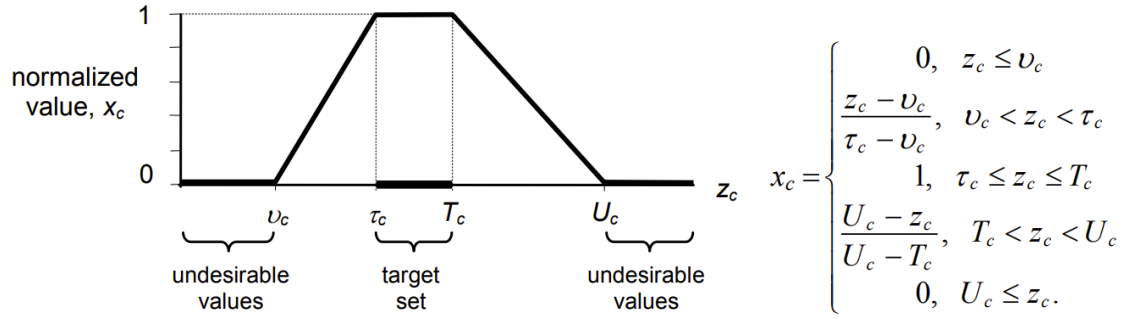


Figure 4. Normalization by linear interpolation for NB

All other basic indicators were normalized in a similar manner based on relevant threshold and target values as shown in Table 1.



Table 1. Target and least desirable values for the indicators, and their normalized values for L'Oréal

	#	Indicator	Type	Values		Explanation	$z_c$	Basis	$x_c$
AIR	1	GHG emissions (tons CO <sub>2</sub> -eq emitted per million dollars of annual net sales)	SB	T <sub>c</sub>	0.623	T is L'Oréal's lowest value within investigated period U is the maximum of all investigated competitor companies (Unilever).	1.12	3 yr avg (2020-2022)	0.946
				U <sub>c</sub>	9.80				
	2	SOx and VOC emissions (tons per million dollars of annual net sales)	SB	T <sub>c</sub>	0.00102	T is 25% of L'Oréal's current value. U is the maximum of all investigated competitor companies (P&G).	0.00460	3 yr avg (2019-2021)	0.964
				U <sub>c</sub>	0.0998				
	3	Energy consumption (MWh per million dollars of annual net sales)	SB	T <sub>c</sub>	23.4	T is L'Oréal's lowest value within the investigated period. U is the average value of ELC and P&G.	25.5	3 yr avg (2020-2022)	0.978
				U <sub>c</sub>	117				
LAND	4	Total waste generation (tons per million dollars of annual net sales)	SB	T <sub>c</sub>	2.10	T is L'Oréal's lowest value within the investigated period. U is the maximum of all investigated competitor companies (P&G).	2.30	3 yr avg (2020-2022)	0.969
				U <sub>c</sub>	8.47				
	5	Waste recycled (%)	LB	υ <sub>c</sub>	90.9	υ is L'Oréal's lowest percentage within the investigated period. τ is the maximum of all investigated competitor companies (P&G).	96.3	3 yr avg (2020-2022)	0.635
				τ <sub>c</sub>	99.4				
	6	Hazardous waste generated (tons per million dollars of annual net sales)	SB	T <sub>c</sub>	0.0810	T is the minimum of industry. U is the maximum of all investigated competitor companies (P&G).	0.560	3 yr avg (2020-2022)	0.375
				U <sub>c</sub>	0.847				
WATER	7	Water use for production (m <sup>3</sup> per ton of bulk product)	SB	T <sub>c</sub>	1.51	T is L'Oréal's 2030 corporate goal to reduce water use by 30% from 2019. <sup>5</sup> U is the maximum of all investigated competitor companies (P&G).	2.11	3 yr avg (2020-2022)	0.799
				U <sub>c</sub>	4.50				

<sup>5</sup> Goal is part of the L'Oréal for the Future program created in 2020; L'Oréal 2022 Universal Registration Document (pg 174)

	8	Water treatment/recycling (% of total site locations)	LB	$v_c$	12.0	$v$ is L'Oréal's lowest percentage within the investigated period. $\tau$ is L'Oréal's 2030 corporate goal to have 100% of the water used in industrial processes recycled and reused in a loop, i.e. 100% of factories will be Waterloop factories.	13.3	3 yr avg (2020-2022)	0.015
				$\tau_c$	100				
	9	COD after treatment (kg/ton product)	SB	$T_c$	1.00	T is based on L'Oreal's internal standard U is the L'Oréal's highest value within investigated period.	4.96	3 yr avg (2022-2022)	0.772
				$U_c$	18.4				
POLIC	10	People who gained access to employment from disadvantaged communities (% of total employee)	LB	$v_c$	0.204	$v$ is L'Oréal's lowest value within the investigated period. $\tau$ is L'Oréal's highest value within the investigated period	0.516	3 yr avg (2022-2022)	0.320
				$\tau_c$	1.18				
	11	Female ratio (percent of females in strategic positions)	NB	$v_c$	29	$v$ is the average in the beauty and cosmetics industry $\tau$ is L'Oréal's maximum value. T is an ideal half-gender representation. U is when all employees were female.	48.3	3 yr avg (2020-2022)	0.965
				$\tau_c$	49				
				$T_c$	50				
				$U_c$	100				
PR(W EALT H))	12	Debt-to-equity ratio	SB	$T_c$	0	T represents a company with the lowest possible leverage. U is the maximum of all investigated competitor companies (P&G).	0.190	3 yr avg (2020-2022)	0.587
				$U_c$	0.46				
	13	Tax revenue (percent of annual sales)	NB	$v_c$	0	$v$ is zero tax. $\tau$ is the maximum of all investigated competitor companies (P&G). T is L'Oréal's maximum value within the investigated period. U is 100% tax.	6.80	3 yr avg (2020-2022)	1.00
				$\tau_c$	4.0				
				$T_c$	7.0				
				$U_c$	100				
ST(WE ALTH)	14	Net sales revenue per employee (million \$ per year)	LB	$v_c$	0.320	$v$ is L'Oréal's lowest value within the investigated period.	0.430	3 yr avg (2020-2022)	0.252

				$\tau_c$	0.757	$\tau$ is the maximum of all investigated competitor companies (P&G).			
	15	Total asset per employee (€)	LB	$v_c$	0.399	$v$ is L'Oréal's lowest value within investigated period. $\tau$ is L'Oréal's highest value within investigated period.	0.517	3 yr avg (2020-2022)	0.861
				$\tau_c$	0.536				
RE(W EALT H)	16	Dividends per million euros of annual net sales	LB	$v_c$	0.0146	$v$ is L'Oréal's lowest value within investigated period. $\tau$ is L'Oréal's highest value within investigated period.	0.0253	3 yr avg (2020-2022)	0.863
				$\tau_c$	0.0270				
	17	Marketing (% of sales)	NB	$v_c$	5	$v$ is the industry standard for growth. $\tau$ is the industry standard for maintaining the company. $T$ is the lowest percentage L'Oréal paid for marketing. $U$ is the highest amount as a percentage of its sales L'Oréal paid for marketing.	31.8	3 yr avg (2020-2022)	0.263
				$\tau_c$	10				
				$T_c$	29				
				$U_c$	32.8				
HEAL TH	18	CPMP	SB	$T_c$	0	$T$ has zero complaints. $U$ is L'Oréal's highest value within investigated period.	46.0	3 yr avg (2020-2022)	0.115
				$U_c$	52				
	19	Social auditing suppliers on the Fundamental Conventions of the ILO (audits/supplier* year)	NB	$v_c$	0	$v$ is the worst minimum possible value $\tau$ is the L'Oréal's average value over 2013-2022 $T$ is the typical number of audits that a factory undergoes according to WRAP. <sup>6</sup> $U$ is the maximum value according to WRAP.	2.00	3 yr avg (2020-2022)	0.930
				$\tau_c$	2.15				
				$T_c$	4				
				$U_c$	16				
	20	Rate of absenteeism due to sickness(%)	SB	$T_c$	2.15	$T$ is the minimum of L'Oréal's value within investigated period. $U$ is the maximum of L'Oréal's value within investigated period.	2.30	3 yr avg (2020-2022)	0.712
				$U_c$	2.67				
KNO W	21	Hours of training per employee (hr per year)	LB	$v_c$	25.4	$v$ is L'Oréal's lowest value within investigated period.	36.2	3 yr avg (2020-2022)	0.280

<sup>6</sup> [https://wrapcompliance.org/wp-content/uploads/2023/10/How-Many-Social-Audits-Are-Enough-WRAP-Oct-2023\\_.pdf](https://wrapcompliance.org/wp-content/uploads/2023/10/How-Many-Social-Audits-Are-Enough-WRAP-Oct-2023_.pdf)

				$\tau_c$	64	$\tau$ is the maximum of all investigated competitor companies (P&G).			
	22	Public expenditure on R&D (% of sales)	LB	$v_c$	1.5	$v$ is the minimum value of all investigated competitor companies (Unilever). $\tau$ is the highest value of L'Oréal.	3.40	3 yr avg (2020-2022)	0.864
				$\tau_c$	3.7				

The normalized basic indicators were fuzzified using membership functions of different sets of linguistic variables, “weak” (W), “medium” (M), and “strong” (S). A membership function with a pick value of 0.7 was chosen for the fuzzification, which is shown in Figure 5. The membership functions have the following equation:

$$\text{For } 0 \leq x \leq 0.7, \mu_W(x) = \frac{0.7-x}{0.7}; \mu_M(x) = \frac{x}{0.7}$$

$$\text{For } 0.7 < x \leq 1.0, \mu_M(x) = \frac{1-x}{0.3}; \mu_S(x) = \frac{x-0.7}{0.3}$$

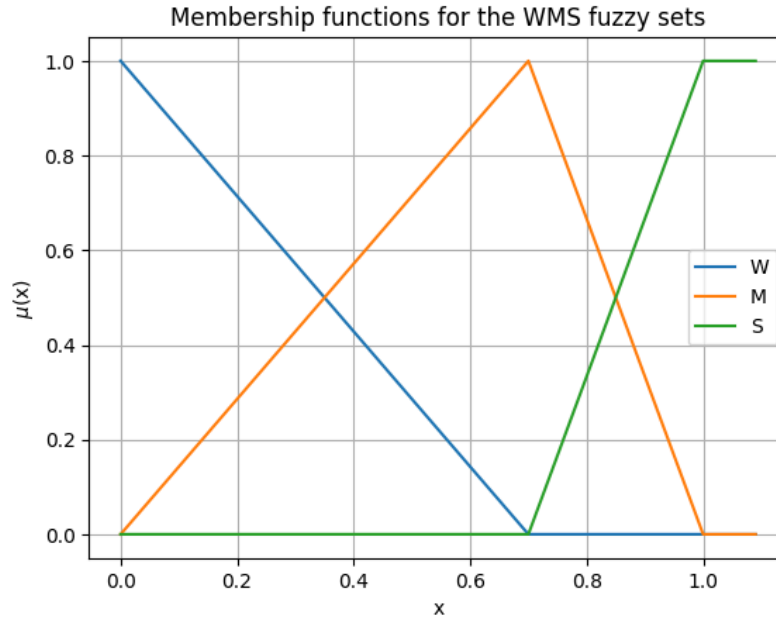


Figure 5. Membership functions for the WMS fuzzy sets

The GHG emissions indicator has a normalized value of  $x=0.946$ , which lies above 0.7. Therefore, its fuzzy set is:

$$\mu_M(x) = \frac{1-0.946}{0.3} = 0.181 \text{ and } \mu_S(x) = \frac{0.946-0.7}{0.3} = 0.819$$

The rest of the normalized values of the basic indicators are fuzzified likewise, as shown in Table 2.

Table 2. Fuzzification of basic inputs

	#	Indicator	$x_c$	Fuzzy set		
				W	M	S
AIR	1	GHG emissions	0.946	0.000	0.181	0.819

	2	SOx, NOx and VOC emissions	0.964	0.000	0.121	0.879
	3	Energy consumption	0.978	0.000	0.0748	0.925
LAND	4	Total waste generation	0.969	0.000	0.105	0.895
	5	Waste recycled	0.635	0.092	0.908	0.000
	6	Hazardous waste	0.375	0.465	0.535	0.000
WATER	7	Water use for production	0.799	0.000	0.671	0.329
	8	Water treated/recycled	0.0148	0.979	0.021	0.000
	9	COD	0.772	0.000	0.759	0.241
POLIC	10	People who gained access to employment from disadvantaged communities (% of total employees)	0.320	0.543	0.457	0.000
	11	Female ratio	0.965	0.000	0.117	0.883
PR(WEALTH)	12	Debt-to-equity ratio	0.587	0.161	0.839	0.000
	13	Tax revenue	1.000	0.000	0.000	1.000
ST(WEALTH)	14	Revenue per employee	0.252	0.640	0.360	0.000
	15	Total asset	0.861	0.000	0.462	0.538
RE(WEALTH)	16	Dividends per million euros of sales	0.863	0.000	0.457	0.543
	17	Marketing (% of sales)	0.263	0.624	0.376	0.000
HEALTH	18	Social auditing suppliers on the Fundamental Conventions of the ILO	0.115	0.835	0.165	0.000
	19	CPMP	0.930	0.000	0.233	0.767
	20	Rate of absenteeism due to sickness	0.712	0.000	0.962	0.0385
KNOW	21	Hours of training per employee	0.280	0.600	0.400	0.000
	22	R&D expenditure	0.864	0.000	0.455	0.545

## Fuzzy and Crisp Values of Secondary Indicators

### 1) Rule base firing

The basic indicators' fuzzy values are utilized as inputs for a rule base, housing "if-then" rules connecting output and input linguistic values. This process is known as an inference engine, which quantifies the fuzzy output by associating it with membership grades corresponding to linguistic values. In a Takagi-Sugeno-Kang (TSK) fuzzy system, such as ours, the output's membership grade from a rule-firing is determined by multiplying its input membership grades. For the secondary indicator AIR, for instance, the same weight was given to all of the indicators in AIR. The rule base is constructed slightly pessimistic. The rule bases are generated by assigning a linguistic value to

$$SUM = L\_GHG + L\_AIREMISS + L\_ENERGY \text{ where } L_{AIR} = \{0 = W, 1 = M, 2 = S\}.$$

The rules are given by:

$$\begin{aligned} AIR &= VB, 0 \leq SUM \leq 1 \\ B, 2 \leq SUM \leq 3 \\ A, SUM &= 4 \\ G, SUM &= 5 \\ VG, SUM &= 6 \end{aligned}$$

For AIR indicator, Rules 14, 15, 17, 18, 23, 24, 26, and 27 fire based on the fuzzy input set of:

GHG emission	M(0.181) and S(0.819)
SOx and VOC emission	M(0.121) and S(0.879)
Energy consumption	M(0.0748) and S(0.925)

Table 3. AIR rule base

Rule #	IF	GHG emissions	AND	SOx and VOC emissions	AND	Energy consumption	THEN	AIR	
1		W		W		W		VB	
2		W		W		M		VB	
3		W		W		S		B	
4		W		M		W		VB	
5		W		M		M		B	
6		W		M		S		B	
7		W		S		W		B	
8		W		S		M		B	

9		W		S		S		A	
10		M		W		W		VB	
11		M		W		M		B	
12		M		W		S		B	
13		M		M		W		B	
14		<b>M</b>	<b>0.181</b>	<b>M</b>	<b>0.121</b>	<b>M</b>	<b>0.0748</b>	<b>B</b>	<b>0.00163</b>
15		<b>M</b>	<b>0.181</b>	<b>M</b>	<b>0.121</b>	<b>S</b>	<b>0.925</b>	<b>A</b>	<b>0.0202</b>
16		M		S		W		B	
17		<b>M</b>	<b>0.181</b>	<b>S</b>	<b>0.879</b>	<b>M</b>	<b>0.0748</b>	<b>A</b>	<b>0.0119</b>
18		<b>M</b>	<b>0.181</b>	<b>S</b>	<b>0.879</b>	<b>S</b>	<b>0.925</b>	<b>G</b>	<b>0.147</b>
19		S		W		W		B	
20		S		W		M		B	
21		S		W		S		A	
22		S		M		W		B	
23		<b>S</b>	<b>0.819</b>	<b>M</b>	<b>0.121</b>	<b>M</b>	<b>0.0748</b>	<b>A</b>	<b>0.00740</b>
24		<b>S</b>	<b>0.819</b>	<b>M</b>	<b>0.121</b>	<b>S</b>	<b>0.925</b>	<b>G</b>	<b>0.0916</b>
25		S		S		W		A	
26		<b>S</b>	<b>0.819</b>	<b>S</b>	<b>0.879</b>	<b>M</b>	<b>0.0748</b>	<b>G</b>	<b>0.0539</b>
27		<b>S</b>	<b>0.819</b>	<b>S</b>	<b>0.879</b>	<b>S</b>	<b>0.925</b>	<b>VG</b>	<b>0.667</b>

Following the individual rule-firing, the fuzzy values of AIR was computed by summing up the output linguistic variables and the corresponding membership grades. The fuzzy values of AIR are:

VB	0
B	0.00163
A	0.0202+0.0119+0.00740=0.0395
G	0.147+0.0916+0.0539=0.292
VG	0.667

Table 4. Fuzzy value of AIR

## 2) Defuzzification

Using the equation below, the fuzzy values of the secondary indicators are converted to crisp values.

$$y_j^{crisp} = \frac{\sum_{all\ i} PV_i \mu_i(y_j^{fuzzy})}{\sum_{all\ i} \mu_i(y_j^{fuzzy})}, \text{ where } PV_i \text{ are the peak values of each of the linguistic values}$$



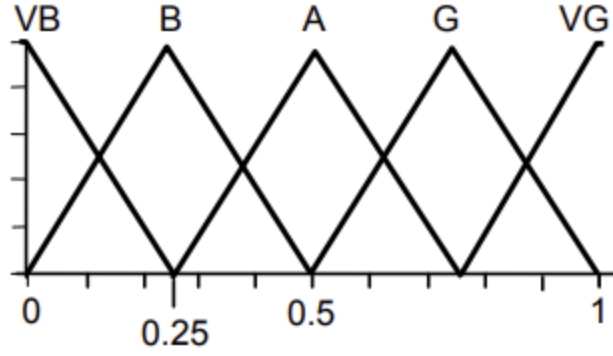


Figure 6. Membership functions for the VBBAGVG fuzzy sets

The VBBAGVG linguistic variables are characterized by peak values falling within the range of 0 to 1. Increments of 0.25 were used for these peaks (Figure 6). Thus, the crisp value of AIR is:

$$y_{AIR}^{crisp} = \frac{(PV)_B \mu_B + (PV)_A \mu_A + (PV)_G \mu_G + (PV)_{VG} \mu_{VG}}{\mu_B + \mu_A + \mu_G + \mu_{VG}} = \frac{0.25(0.00163) + 0.5(0.0395) + 0.75(0.292) + 1(0.667)}{0.00163 + 0.0395 + 0.292 + 0.667} = 0.906$$

The crisp values of the other secondary indicators were calculated similarly (Table 5) using the rule bases presented in the Appendix.

Table 5. Fuzzy and crisp values for all secondary indicators

Secondary indicator	Fuzzy value	Crisp value
AIR	B(0.00163) A(0.0395) G(0.292) VG(0.667)	0.906
LAND	VB(0.00450) B(0.561) A(0.435)	0.358
WATER	B(0.498) A(0.414) G(0.0864) VG(0.00168)	0.398
POLIC	B(0.0634) A(0.533) G(0.403)	0.585
HEALTH	B(0.847) A(0.148) G(0.00487)	0.289
KNOW	B(0.273) A(0.509) G(0.218)	0.486
PR(WEALTH)	A(0.161) G(0.839)	0.710
ST(WEALTH)	B(0.296) A(0.511) G(0.193)	0.474
RE(WEALTH)	B(0.285) A(0.511) G(0.204)	0.480

## Fuzzy and Crisp Values of Primary Indicators

The inference engines for ECOS, HUMS, and WEALTH use a rule base with  $5^3=125$  rules since they have three inputs each with five linguistic values. The rule base for ECOS was constructed so that the AIR weighs twice as much as LAND and WATER.

Let  $SUM = L_{AIR} + L_{LAND} + L_{WATER}$

where  $L_{AIR} = \{VB=0, B=2, A=4, G=6, VG=8\}$

$L_{LAND \text{ or } WATER} = \{VB=0, B=1, A=2, G=3, VG=4\}$

The following rule base was constructed for ECOS:

$ECOS = VB, 0 \leq SUM \leq 3$

$B, 4 \leq SUM \leq 7$

$A, 8 \leq SUM \leq 11$

$G, 12 \leq SUM \leq 14$

$VG, 15 \leq SUM \leq 16$

From this pessimistic rule base, a total of  $4 \times 3 \times 4 = 48$  rules fired (Table 6).

Table 6. Rules that fire in calculating ECOS

Rule #	IF AIR is		and LAND is		and WATER is		$L_{AIR}$	$L_{LAND}$	$L_{WATER}$	SUM	THEN ECOS	
1	B	0.00163	VB	0.00450	B	0.498	2	0	1	3	VB	0.00000365
2	B	0.00163	VB	0.00450	A	0.414	2	0	2	4	B	0.00000303
3	B	0.00163	VB	0.00450	G	0.0864	2	0	3	5	B	0.000000634
4	B	0.00163	VB	0.00450	VG	0.00168	2	0	4	6	B	0.0000000123
5	B	0.00163	B	0.561	B	0.498	2	1	1	4	B	0.000456
6	B	0.00163	B	0.561	A	0.414	2	1	2	5	B	0.000378
7	B	0.00163	B	0.561	G	0.0864	2	1	3	6	B	0.0000790
8	B	0.00163	B	0.561	VG	0.00168	2	1	4	7	B	0.00000153
9	B	0.00163	A	0.435	B	0.498	2	2	1	5	B	0.000354
10	B	0.00163	A	0.435	A	0.414	2	2	2	6	B	0.000293
11	B	0.00163	A	0.435	G	0.0864	2	2	3	7	B	0.0000613
12	B	0.00163	A	0.435	VG	0.00168	2	2	4	8	A	0.00000119
13	A	0.0395	VB	0.00450	B	0.498	4	0	1	5	B	0.0000884
14	A	0.0395	VB	0.00450	A	0.414	4	0	2	6	B	0.0000734
15	A	0.0395	VB	0.00450	G	0.0864	4	0	3	7	B	0.0000153
16	A	0.0395	VB	0.00450	VG	0.00168	4	0	4	8	A	0.000000
17	A	0.0395	B	0.561	B	0.498	4	1	1	6	B	0.0110
18	A	0.0395	B	0.561	A	0.414	4	1	2	7	B	0.00915
19	A	0.0395	B	0.561	G	0.0864	4	1	3	8	A	0.00191
20	A	0.0395	B	0.561	VG	0.00168	4	1	4	9	A	0.0000370
21	A	0.0395	A	0.435	B	0.498	4	2	1	7	B	0.00855
22	A	0.0395	A	0.435	A	0.414	4	2	2	8	A	0.00710

23	A	0.0395	A	0.435	G	0.0864	4	2	3	9	A	0.00148
24	A	0.0395	A	0.435	VG	0.00168	4	2	4	10	A	0.0000287
25	G	0.292	VB	0.00450	B	0.498	6	0	1	7	B	0.000655
26	G	0.292	VB	0.00450	A	0.414	6	0	2	8	A	0.000544
27	G	0.292	VB	0.00450	G	0.0864	6	0	3	9	A	0.000114
28	G	0.292	VB	0.00450	VG	0.00168	6	0	4	10	A	0.00000220
29	G	0.292	B	0.561	B	0.498	6	1	1	8	A	0.0817
30	G	0.292	B	0.561	A	0.414	6	1	2	9	A	0.0678
31	G	0.292	B	0.561	G	0.0864	6	1	3	10	A	0.0142
32	G	0.292	B	0.561	VG	0.00168	6	1	4	11	A	0.000275
33	G	0.292	A	0.435	B	0.498	6	2	1	9	A	0.0634
34	G	0.292	A	0.435	A	0.414	6	2	2	10	A	0.0526
35	G	0.292	A	0.435	G	0.0864	6	2	3	11	A	0.0110
36	G	0.292	A	0.435	VG	0.00168	6	2	4	12	G	0.000213
37	VG	0.667	VB	0.00450	B	0.498	8	0	1	9	A	0.00149
38	VG	0.667	VB	0.00450	A	0.414	8	0	2	10	A	0.00124
39	VG	0.667	VB	0.00450	G	0.0864	8	0	3	11	A	0.000259
40	VG	0.667	VB	0.00450	VG	0.00168	8	0	4	12	G	0.00000502
41	VG	0.667	B	0.561	B	0.498	8	1	1	10	A	0.186
42	VG	0.667	B	0.561	A	0.414	8	1	2	11	A	0.155
43	VG	0.667	B	0.561	G	0.0864	8	1	3	12	G	0.0323
44	VG	0.667	B	0.561	VG	0.00168	8	1	4	13	G	0.000626
45	VG	0.667	A	0.435	B	0.498	8	2	1	11	A	0.144
46	VG	0.667	A	0.435	A	0.414	8	2	2	12	G	0.120
47	VG	0.667	A	0.435	G	0.0864	8	2	3	13	G	0.0250
48	VG	0.667	A	0.435	VG	0.00168	8	2	4	14	G	0.000486

Fuzzy values of ECOS were calculated as **B(0.0312)**, **A(0.790)**, and **G(0.179)**, which yielded a crisp value of **0.537**.

Similarly, the rule base for HUMS was constructed so that POLIC weighs twice as much as HEALTH and KNOW.

Let  $SUM = L_{POLIC} + L_{HEALTH} + L_{KNOW}$

where  $L_{POLIC} = \{VB=0, B=2, A=4, G=6, VG=8\}$  and  $L_{Others} = \{VB=0, B=1, A=2, G=3, VG=4\}$

$HUMS = VB, 0 \leq SUM \leq 3$

$B, 4 \leq SUM \leq 7$

$A, 8 \leq SUM \leq 11$   
 $G, 12 \leq SUM \leq 14$   
 $VG, 15 \leq SUM \leq 16$

From this rule base, a total of  $3*3*3=27$  rules fired and the fuzzy value of HUMS was determined to be **B(0.438), A(0.561), and G(0.000428)**, which corresponds to a crisp value of **0.391**.

For WEALTH, the rules base was constructed so that PR, ST, and RE weigh the same as following:

Let  $SUM = L_{PR} + L_{ST} + L_{RE}$

where  $L_i = \{VB=0, B=1, A=2, G=3, VG=4\}$

$WEALTH = VB, 0 \leq SUM \leq 2$

$B, 3 \leq SUM \leq 5$

$A, 6 \leq SUM \leq 8$

$G, 9 \leq SUM \leq 10$

$VG, 11 \leq SUM \leq 12$

From this pessimistic rule base, the fuzzy values of WEALTH were calculated as **B(0.132), A(0.835), and G(0.0331)** which yielded a crisp value of **0.475**. Table 7 shows the fuzzy values and crisp values for the two primary indicators.

Table 7. Fuzzy and crisp values of all primary indicators

Primary indicator	Fuzzy value	Crisp value
ECOS	B(0.00312) A(0.790) G(0.179)	0.537
HUMS	B(0.439) A(0.561) G(0.000427)	0.391
WEALTH	B(0.132) A(0.835) G(0.0331)	0.475

## Overall Sustainability (OSUS)

Finally, the two primary indicators, ECOS and HUMS, were combined to yield overall sustainability, OSUS. Equal weights were placed on all of the primary indicators.

Let  $SUM = L_{ECOS} + L_{HUMS} + L_{WEALTH}$ , where  $L_i = \{VB=0, B=1, A=2, G=3, VG=4\}$

The range of possible SUM values were distributed as follows:

$OSUS = EL, 0 \leq SUM \leq 1$

$VL, 2 \leq SUM \leq 3$

$L, SUM = 4$

$FL, SUM = 5$

$I, SUM = 6$

$FH, SUM = 7$

$H, SUM = 8$

$VH, 9 \leq SUM \leq 10$

$EH, 11 \leq SUM \leq 12$

Based on the rule base we set, we calculated the fuzzy value of OSUS (Table 8).

Table 8. Rules that fire in calculating OSUS

Rule #	If ECOS is		And HUMS is		And WEALTH is		$L_{ECOS}$	$L_{HUMS}$	$L_{WEALTH}$	SUM	Then OSUS	
1	B	0.0312	B	0.439	B	0.132	1	1	1	3	VL	0.00181
2	B	0.0312	B	0.439	A	0.835	1	1	2	4	L	0.0114
3	B	0.0312	B	0.439	G	0.0331	1	1	3	5	FL	0.000452
4	B	0.0312	A	0.561	B	0.132	1	2	1	4	L	0.00232
5	B	0.0312	A	0.561	A	0.835	1	2	2	5	FL	0.0146
6	B	0.0312	A	0.561	G	0.0331	1	2	3	6	I	0.000579
7	B	0.0312	G	0.000427	B	0.132	1	3	1	5	FL	0.00000177
8	B	0.0312	G	0.000427	A	0.835	1	3	2	6	I	0.0000111
9	B	0.0312	G	0.000427	G	0.0331	1	3	3	7	FH	0.000000442
10	A	0.790	B	0.439	B	0.132	2	1	1	4	L	0.0458
11	A	0.790	B	0.439	A	0.835	2	1	2	5	FL	0.289
12	A	0.790	B	0.439	G	0.0331	2	1	3	6	I	0.0115
13	A	0.790	A	0.561	B	0.132	2	2	1	5	FL	0.0587
14	A	0.790	A	0.561	A	0.835	2	2	2	6	I	0.370
15	A	0.790	A	0.561	G	0.0331	2	2	3	7	FH	0.0147
16	A	0.790	G	0.000427	B	0.132	2	3	1	6	I	0.0000448
17	A	0.790	G	0.000427	A	0.835	2	3	2	7	FH	0.000282
18	A	0.790	G	0.000427	G	0.0331	2	3	3	8	H	0.0000112
19	G	0.179	B	0.439	B	0.132	3	1	1	5	FL	0.0104
20	G	0.179	B	0.439	A	0.835	3	1	2	6	I	0.0653
21	G	0.179	B	0.439	G	0.0331	3	1	3	7	FH	0.00259
22	G	0.179	A	0.561	B	0.132	3	2	1	6	I	0.0133
23	G	0.179	A	0.561	A	0.835	3	2	2	7	FH	0.0837
24	G	0.179	A	0.561	G	0.0331	3	2	3	8	H	0.00332
25	G	0.179	G	0.000427	B	0.132	3	3	1	7	FH	0.0000101
26	G	0.179	G	0.000427	A	0.835	3	3	2	8	H	0.0000638

27	G	0.179	G	0.000427	G	0.0331	3	3	3	9	VH	0.00000253
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The fuzzy value of OSUS was calculated to be **VL(0.00181)**, **L(0.0596)**, **FL(0.373)**, **I(0.461)**, **FH(0.101)**, and **H(0.00339)** by summing all individual rule-firing outputs. The crisp value for OSUS was obtained using height defuzzification:

$$y_{OSUS} = \frac{(PV)_{VL}\mu_{VL} + (PV)_L\mu_L + (PV)_{FL}\mu_{FL} + (PV)_I\mu_I + (PV)_{FH}\mu_{FH} + (PV)_H\mu_H}{\mu_{VL} + \mu_L + \mu_{FL} + \mu_I + \mu_{FH} + \mu_H}$$

Where peak values were obtained from Figure 7.

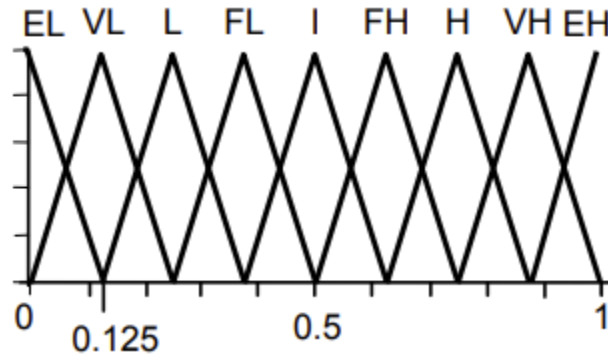


Figure 7. Membership functions for the ELVLLFLIFHHVHEH fuzzy sets

The final crisp value for L'Oréal's overall sustainability was calculated as:

$$y_{OSUS} = \frac{(0.025)(0.00181) + (0.25)(0.0596) + (0.375)(0.373) + (0.5)(0.461) + (0.625)(0.101) + (0.75)(0.00339)}{0.00181 + 0.0596 + 0.373 + 0.461 + 0.101 + 0.00339} = 0.451$$

# Results

Overall sustainability of L'Oréal was found to be 0.451 on a scale from 0 to 1. This score suggests that L'Oréal's sustainability level falls within the range of fairly low to intermediate. Table 9 compiles all the crisp values of basic indicators, secondary indicators, primary indicators, and the final overall sustainability indicator. The top five crisp values of the basic indicators are highlighted in green and the lowest two crisp values are highlighted in red. Of the three primary indicators, L'Oréal performs worst on the HUMS. This is largely due to L'Oréal's high CPMP value which is not desirable. In terms of the crisp values for the secondary indicators, the best-performing indicator was AIR followed by PR(WEALTH). For PR(WEALTH) the best-performing basic indicator was the tax revenue. The worst performing indicators were HEALTH followed by LAND and WATER.

Table 9. Summary of crisp values for all indicators

	Primary indicators	Secondary indicators		Basic indicators	
OSUS 0.451	ECOS 0.537	AIR	0.906	GHG emissions (tons CO2-eq emitted per million dollars of annual net sales)	0.946
				SOx and VOC emissions (tons per million dollars of annual net sales)	0.964
				Energy consumption (MWh per million dollars of annual net sales)	0.978
		LAND	0.358	Total waste generation (tons per million dollars of annual net sales)	0.969
				Waste recycled (%)	0.635
				Hazardous waste generated (tons per million dollars of annual net sales)	0.375
		WATER	0.398	Water use for production (m3 per ton of bulk product)	0.799
				Water treatment/recycling (% of total site locations)	0.015
				COD after treatment (kg/ton product)	0.772
	HUMS 0.390	POLIC	0.585	People who gained access to employment from disadvantaged communities (% of total employees)	0.320
				Female ratio (percent of females in strategic positions)	0.965
		HEALTH	0.289	CPMP	0.115
				Social auditing suppliers on the Fundamental Conventions of the ILO (audits/supplier* year)	0.930

				Rate of absenteeism due to sickness(%)	0.712
		KNOW	0.486	Hours of training per employee (hr per year)	0.280
				Public expenditure on R&D (% of sales)	0.864
	WEALTH 0.475	PR(WEALTH)	0.710	debt-to-equity ratio	0.587
				Tax revenue (percent of annual sales)	1.000
		ST(WEALTH)	0.474	Net sales revenue per employee (million \$ per year)	0.252
				Total asset per employee (euros)	0.861
		RE(WEALTH)	0.480	Dividends per million euros of annual net sales	0.863
				Marketing (% of sales)	0.263

Sensitivity analysis was conducted to determine the effects of changing each of the sustainability indicators on the overall sustainability as shown in Table 10 (Appendix 12 has more detailed spreadsheet). The result can be used in determining necessary policies and actions for the sustainable development of a corporation. The normalized values for basic indicators were perturbed by  $\pm 10\%$  to study their effects on OSUS. The cases that affect OSUS the most are highlighted in green and those that have the least effects are highlighted in red. Change in tax revenue has a negligible impact on the overall sustainability of L'Oréal. The model has the most sensitivity to changes in water use for production, COD after treatment, and the percentage of people who gained access to employment from disadvantaged communities. This means that small changes in these indicators will result in a large improvement in the overall sustainability of the corporation. Therefore, It is recommended to create more opportunities for people from socially or financially disadvantaged communities and decrease the water use and COD release for L'Oréal.

Table 10. Sensitivity analysis

Indicator index	Indicator	$x_c$	-10%	+10%
			$ D_c $	
1	GHG emissions (tons CO2-eq emitted per million dollars of annual net sales)	0.9458	0.0007	0.0004
2	SOx and VOC emissions (tons per million dollars of annual net sales)	0.9638	0.0005	0.0002
3	Energy consumption (MWh per million dollars of annual net sales)	0.9776	0.0004	0.0001
4	Total waste generation (tons per million dollars of annual net sales)	0.9686	0.0002	0.0001
5	Waste recycled (%)	0.6353	0.0006	0.0006
6	Hazardous waste generated (tons per million dollars of annual net sales)	0.3747	0.0010	0.0010



	sales)			
7	Water use for production (m3 per ton of bulk product)	0.7987	0.0022	0.0022
8	Water treatment/recycling (% of total site locations)	0.0148	0.0001	0.0001
9	COD after treatment (kg/ton product)	0.7724	0.0024	0.0025
10	Access to employment from disadvantaged communities (%)	0.3197	0.0025	0.0025
11	Female ratio (%)	0.9650	0.0007	0.0002
12	debt-to-equity ratio	0.5870	0.0015	0.0015
13	Tax revenue (percent of annual sales)	1.0000	0.0000	0.0000
14	Net sales revenue per employee (million \$ per year)	0.2517	0.0009	0.0009
15	Total asset per employee (euros)	0.8613	0.0014	0.0014
16	Dividends per million euros of annual net sales	0.8629	0.0014	0.0014
17	Marketing (% of sales)	0.2632	0.0009	0.0009
18	Social auditing supplier on the Fundamental Conventions of the ILO	0.1154	0.0004	0.0004
19	CPMP	0.9302	0.0001	0.0001
20	Rate of absenteeism due to sickness (%)	0.7115	0.0005	0.0018
21	Hours of training per employee	0.2798	0.0010	0.0010
22	R&D expenditure (%)	0.8636	0.0011	0.0011

# Appendices

## Appendix 1. Basic Indicator raw data (2012-2022)

Refer to footnotes for source of data or comments

	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	ELC <sup>7</sup>	P&G <sup>8</sup>	Unilever
Net sales <sup>9</sup> (\$ million)	28,889	30,520	29,952	28,047	28,591	29,415	31,813	33,458	31,975	38,199	40,311	17,737	80,200 <sup>10</sup>	63,293
GHG emission (ton CO <sub>2</sub> -eq)	N/A	N/A	118,900	105,000	114,200	98,000	88,900	80,300	55,800	38,300	25,100	83,900	2,316,000	620,000 <sup>11</sup>
GHG emission (ton/\$ million )	N/A	N/A	3.97	3.74	3.99	3.33	2.79	2.40	1.75	1.00	0.623	4.73	28.9	9.80
SOx and VOC emissions (tons)	131.7	142.7	140.8	156.3	151.3	178	173	173.3	143.4	156.3	N/A	N/A	8,000	N/A
SOx and VOC emissions (tons/\$ million)	0.00456	0.00468	0.00470	0.00557	0.00529	0.00605	0.00544	0.00518	0.00448	0.00409	N/A	N/A	0.0998	N/A
Total energy consumption (MWh)	761,006	795,495	719,398	719,543	733,785	733,122	941,185	931,793	897,048	953,513	944,379	316,000	17,316,667	N/A

<sup>7</sup>[https://media.elcompanies.com/files/e/estee-lauder-companies/universal/our-commitments/2022-si-s-report/sis-performance-summary-report-2022.pdf?\\_ga=2.77588437.1380509512.1699415581-1700349732.1698780099&\\_gl=1\\*1t5wnbl\\*\\_ga\\*MTcwMDM0OTczMi4xNjk4NzgwMDk5\\*\\_ga\\_V9QZ4PSDRY\\*MTY5OTQxNTU4MS4zLjEuMTY5OTQxNTYzMC4xMS4wLjA](https://media.elcompanies.com/files/e/estee-lauder-companies/universal/our-commitments/2022-si-s-report/sis-performance-summary-report-2022.pdf?_ga=2.77588437.1380509512.1699415581-1700349732.1698780099&_gl=1*1t5wnbl*_ga*MTcwMDM0OTczMi4xNjk4NzgwMDk5*_ga_V9QZ4PSDRY*MTY5OTQxNTU4MS4zLjEuMTY5OTQxNTYzMC4xMS4wLjA)

<sup>8</sup> GHG emissions, air emissions, energy consumption, waste recycled, hazardous waste data from [https://s1.q4cdn.com/695946674/files/doc\\_downloads/2022/12/Environmental-Footprint-Metrics-for-PG-Operations\\_2022.pdf](https://s1.q4cdn.com/695946674/files/doc_downloads/2022/12/Environmental-Footprint-Metrics-for-PG-Operations_2022.pdf)

<sup>9</sup> <https://www.macrotrends.net/stocks/charts/LRLCY/L'Oréal-sa/revenue>

<sup>10</sup> <https://us.pg.com/annualreport2022/financial-highlights/>

<sup>11</sup> <https://www.unilever.com/files/92ui5egz/production/257f12db9c95ffa2ed12d6f2e2b3ff67db49fd60.pdf> (pg 40)

Total energy consumption (MWh/\$ million)	26.3	26.1	24.0	25.7	25.7	24.9	29.6	27.8	28.1	25.0	23.4	17.8	216	N/A
Waste generation (tons)	94,236	106,080	97,817	90,587	88,262	87,187	91,050	93,804	85,398	80,363	83,199	31,200	679,000	512,700
Waste generation (tons/\$ million)	3.26	3.48	3.27	3.23	3.09	2.96	2.86	2.80	2.67	2.10	2.06	1.76	8.47	8.10
Waste recycled or reused (%)	95	90.9	91	93	98	96	97	97	96	97	96	71	99.4	N/A
Hazardous waste (tons)	N/A	N/A	N/A	16,140	19,111	18,437	17,774	19,230	17,812	19,875	23,822	1,400	67,900	5,127 <sup>12</sup>
Hazardous waste (tons/\$ million)	N/A	N/A	N/A	0.575	0.668	0.627	0.559	0.575	0.557	0.520	0.591	0.079	0.847	0.0810
Reduction in water use for production from 2010 (%) <sup>13</sup>	4.7	9.5	21.0	32.1	35.8	35.8	35.8	39.5	37.0	42.0	43.2	N/A	27 <sup>14</sup>	42.5 <sup>15</sup>
Water use for production (m <sup>3</sup> per ton of bulk product) <sup>16</sup>	3.40	3.23	2.82	2.42	2.29	2.29	2.29	2.16	2.24	2.07	2.02	N/A	4.50	1.54 <sup>17</sup>
Water	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	12	15	13	N/A	4.0	N/A

<sup>12</sup> <https://www.unilever.com/planet-and-society/waste-free-world/tackling-manufacturing-waste/>

<sup>13</sup> 4.4 m<sup>3</sup>/ton product in 2005 so given 19% reduction in 2010,  $4.4(1-0.19) = 3.564$  m<sup>3</sup>/ton product.

[https://assets.ctfassets.net/ogad6svuzkv/37E5Tetwa4kWywiSO2sSQO/c0387b2ed08295f55e12a79fc99774af/2005\\_Full\\_Sustainability\\_Report.pdf](https://assets.ctfassets.net/ogad6svuzkv/37E5Tetwa4kWywiSO2sSQO/c0387b2ed08295f55e12a79fc99774af/2005_Full_Sustainability_Report.pdf)

<sup>14</sup> Water consumption in 2005 = 83 million m<sup>3</sup>/ton. <https://www.pginvestor.com/esg/environmental/water/data-metrics/default.aspx>

<sup>15</sup>  $1 - (2022/2010) = 1 - (1.54/2.68) = 0.425$ ; unilever-sustainability-performance-data-water.xlsx

<sup>16</sup> <https://core.ac.uk/download/pdf/33158345.pdf> (pg 27)

<sup>17</sup> <https://www.unilever.com/files/6e3ff46-24b4-4367-a8f1-2743f32d9bd7/unilever-s-basis-of-preparation-2022.pdf> (pg 5)

treatment/recycling (% of total site locations)														
Reduction in COD from 2005 (%) <sup>18</sup>	-3.6%	-21.3%	-3.1%	-38%	-53%	-52%	-53%	-59%	-61%	-81%	-80%	N/A	N/A	N/A
COD after treatment (kg/ton product)	18.4	14.48	14.0312	8.6986	8.9582	9.1488	8.9582	7.8146	7.4334	3.6214	3.812	N/A	0.84	0.96
Tax charge (€ million)	1,005.5	1,043.6	1,111.0	1,222.9	1,213.7	901.3	1,284.3	2,100	1,900	2,000	2,400	628	3,202	2,179
Net sales (€ million)	22,462.7	22,124.2	22,532.0	25,257.4	24,916.3	26,023.7	26,937.4	29,873.6	27,992.1	32,287.6	38,260.6	N/A	N/A	N/A
Tax revenue (percent of annual sales)	4.5	4.7	4.9	4.8	4.9	3.5	4.8	7.0	6.8	6.2	6.3	3.5	4.0	3.4
Access to employment from disadvantaged communities	15000	22000	52000	60,600	67533	53,505	63,584	90,635	100,905	13,946	17,827	N/A	N/A	N/A
Disadvantaged community employment ratio	0.207	0.284	0.661	0.731	0.756	0.648	0.739	1.03	1.18	0.163	0.204	N/A	N/A	N/A
Female ratio (percent of females in strategic	N/A	N/A	46	41	42.6	45	45	47	49	48	48	55	50	54

<sup>18</sup> ~19.0624 kg/ton product in 2005

leadership)														
Complaints per Million Products Sold	N/A	N/A	N/A	N/A	52	52	49	47	52	39	46	N/A	N/A	N/A
Absenteeism due to sickness (%)	2.67	2.28	2.36	2.24	2.15	2.24	2.20	2.00	2.00	2.4	2.5	N/A	N/A	N/A
Social auditing supplier on the Fundamental Conventions of the ILO (audits/supplier* year)	N/A	4	2.78	2.38	1.97	1.02	1.51	1.85	1.73	2.96	1.3	N/A	N/A	N/A
Total Asset (in millions of euro)	29234	30878	32058	33711	35630	35339	38457	43810	43607	43013	46844	1176	10173	26686
Total Asset (euro per employee)	0.402	0.399	0.408	0.407	0.399	0.428	0.447	0.498	0.511	0.504	0.536	N/A	N/A	N/A
Marketing (% of sales)	30.1	30	29.1	29.1	29	29.4	30.2	30.8	30.9	32.8	31.7	1.4	4.83	13
Total number of employees	72,637	77,452	78,611	82,881	89,331	82,606	86,030	87,974	85,392	85,412	87,369	63,000	106,000	138,000
Debt to Equity Ratio <sup>19</sup>	0.01	0.01	0.13	0.03	0.05	0.05	0.05	0.1	0.09	0.27	0.21	0.0251	0.46	0.0308
Sales revenue/Employ	0.398	0.394	0.381	0.338	0.320	0.356	0.370	0.380	0.374	0.447	0.461	0.282	0.757	0.459

<sup>19</sup> <https://www.financecharts.com/stocks/LRLCY/value/debt-to-equity-ratio-averages>

ee (\$ million per year)														
Dividends (€) per share	2.30	2.50	2.70	3.10	3.30	3.55	3.85	3.85	4.00	4.80	6.00	2.16 <sup>20</sup>	3.52 <sup>21</sup>	1.48 <sup>22</sup>
Shares	143	146	149	152	155	158	161	164	167	169	172	2,214	2,389,553,883	N/A
Dividends (€) per million sales	0.0146	0.0165	0.0179	0.0187	0.0205	0.0216	0.0230	0.0211	0.0239	0.0251	0.0270	0.250	\$113,140.23	€73,290.00
Training hours (hr per year)	N/A	1,325,136	1,599,742	1,577,490	1,736,034	1,715,698	2,105,950	2,692,570	3,180,718	3,180,718	3,167,802	N/A	N/A	N/A
Number of employees trained	N/A	N/A	N/A	58,683	68,264	64,617	74,506	84,677	86,196	89,613	87,369	N/A	N/A	N/A
Hours of training per employee (hr per year)	N/A	N/A	N/A	26.9	25.4	26.6	28.3	31.8	36.9	35.5	36.3	N/A	64	27
R&D expenditures (% of sales)	3.5	3.7	3.4	3.1	3.3	3.4	3.4	3.3	3.4	3.2	3.7	1.7	2.5	1.5

## Appendix 2. Rule base for LAND

Rule #	IF	Total waste	AND	Waste recycled	AND	Hazardous waste	THEN	LAND	
1		W		W		W		VB	

<sup>20</sup> 2.33 USD converted to euros; Estée Lauder 2022 Annual Report (pg 76)

<sup>21</sup> 3.52 USD converted to euros; Procter & Gamble 2022 Annual Report (pg 2)

<sup>22</sup> Unilever 2022 Annual Report (pg 175)

2		W		W		M		VB	
3		W		W		S		B	
4		W		M		W		VB	
5		W		M		M		B	
6		W		M		S		B	
7		W		S		W		B	
8		W		S		M		B	
9		W		S		S		A	
10		M	0.105	W	0.0924	W	0.465	VB	0.00450
11		M	0.105	W	0.0924	M	0.535	B	0.00518
12		M		W		S		B	
13		M	0.105	M	0.908	W	0.465	B	0.0441
14		M	0.105	M	0.908	M	0.535	B	0.0508
15		M		M		S		A	
16		M		S		W		B	
17		M		S		M		A	
18		M		S		S		G	
19		S	0.895	W	0.0924	W	0.465	B	0.0385
20		S	0.895	W	0.0924	M	0.535	B	0.0443
21		S		W		S		A	
22		S	0.895	M	0.908	W	0.465	B	0.378
23		S	0.895	M	0.908	M	0.535	A	0.435
24		S		M		S		G	
25		S		S		W		A	
26		S		S		M		G	

27		S		S		S		VG	
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### Appendix 3. Rule base for WATER

Rule #	IF	Water use for production	AND	Water recycled	AND	COD	THEN	WATER	
1		W		W		W		VB	
2		W		W		M		VB	
3		W		W		S		B	
4		W		M		W		VB	
5		W		M		M		B	
6		W		M		S		A	
7		W		S		W		B	
8		W		S		M		A	
9		W		S		S		G	
10		M		W		W		VB	
11		M	0.671	W	0.979	M	0.759	B	0.498
12		M	0.671	W	0.979	S	0.241	A	0.159
13		M		M		W		B	
14		M	0.671	M	0.0211	M	0.759	A	0.0107
15		M	0.671	M	0.0211	S	0.241	G	0.00342
16		M		S		W		A	
17		M		S		M		G	
18		M		S		S		VG	
19		S		W		W		B	
20		S	0.329	W	0.979	M	0.759	A	0.244



21		S	0.329	W	0.979	S	0.241	G	0.0777
22		S		M		W		A	
23		S	0.329	M	0.0211	M	0.759	G	0.00527
24		S	0.329	M	0.0211	S	0.241	VG	0.00168
25		S		S		W		G	
26		S		S		M		VG	
27		S		S		S		VG	

Appendix 4. Rule base for HEALTH

Rule #	IF	CPMP	AND	Auditing	AND	Absence rate	THEN	HEALTH	
1		W		W		W		VB	
2		W		W		M		VB	
3		W		W		S		B	
4		W		M		W		VB	
5		W	0.835	M	0.233	M	0.962	B	0.187
6		W	0.835	M	0.233	S	0.0385	B	0.00747
7		W		S		W		B	
8		W	0.835	S	0.767	M	0.962	B	0.616
9		W	0.835	S	0.767	S	0.0385	A	0.0247
10		M		W		W		VB	
11		M		W		M		B	
12		M		W		S		B	
13		M		M		W		B	
14		M	0.165	M	0.233	M	0.962	B	0.0369
15		M	0.165	M	0.233	S	0.0385	A	0.00147

16		M		S		W		B	
17		<b>M</b>	<b>0.165</b>	<b>S</b>	<b>0.767</b>	<b>M</b>	<b>0.962</b>	<b>A</b>	<b>0.122</b>
18		<b>M</b>	<b>0.165</b>	<b>S</b>	<b>0.767</b>	<b>S</b>	<b>0.0385</b>	<b>G</b>	<b>0.00487</b>
19		S		W		W		B	
20		S		W		M		B	
21		S		W		S		A	
22		S		M		W		B	
23		S		M		M		A	
24		S		M		S		G	
25		S		S		W		A	
26		S		S		M		G	
27		S		S		S		VG	

Appendix 5. Rule base for POLIC

Rule #	IF	Disadvantaged communities	AND	Female ratio	THEN	POLIC	
1		W		W		VB	
2		<b>W</b>	<b>0.543</b>	<b>M</b>	<b>0.117</b>	<b>B</b>	<b>0.0634</b>
3		<b>W</b>	<b>0.543</b>	<b>S</b>	<b>0.883</b>	<b>A</b>	<b>0.480</b>
4		M		W		B	
5		<b>M</b>	<b>0.457</b>	<b>M</b>	<b>0.117</b>	<b>A</b>	<b>0.0533</b>
6		<b>M</b>	<b>0.457</b>	<b>S</b>	<b>0.883</b>	<b>G</b>	<b>0.403</b>
7		S		W		A	
8		S		M		G	
9		S		S		VG	

Appendix 6. Rule base for KNOW

Rule #	IF	Training	AND	R&D	THEN	KNOW	
1		W		W		VB	
2		W	0.600	M	0.455	B	0.273
3		W	0.600	S	0.545	A	0.327
4		M		W		B	
5		M	0.400	M	0.455	A	0.182
6		M	0.400	S	0.545	G	0.218
7		S		W		A	
8		S		M		G	
9		S		S		VG	

Appendix 7. Rule base for PR(WEALTH)

Rule #	IF	Debt-to-equity	AND	Tax revenue	THEN	PR(WEALTH)	
1		W		W		VB	
2		W		M		B	
3		W	0.161	S	1.000	A	0.161
4		M		W		B	
5		M		M		A	
6		M	0.839	S	1.000	G	0.839
7		S		W		A	
8		S		M		G	
9		S		S		VB	

Appendix 8. Rule base for ST(WEALTH)

Rule #	IF	Sales revenue	AND	Total asset	THEN	ST(WEALTH)	
1		W		W		VB	
2		W	0.640	M	0.462	B	0.296
3		W	0.640	S	0.538	A	0.344
4		M		W		B	
5		M	0.360	M	0.462	A	0.166
6		M	0.360	S	0.538	G	0.193
7		S		W		A	
8		S		M		G	
9		S		S		VG	

Appendix 9. Rule base for RE(WEALTH)

Rule #	IF	Dividends	AND	Marketing	THEN	ST(WEALTH)	
1		W		W		VB	
2		W		M		B	
3		W		S		A	
4		M	0.457	W	0.624	B	0.285
5		M	0.457	M	0.376	A	0.172
6		M		S		G	
7		S	0.543	W	0.624	A	0.339
8		S	0.543	M	0.376	G	0.204
9		S		S		VG	

Appendix 10. Fired rule base for HUMS

Rule #	IF POLIC is		and HEALTH is		and KNOW is		L <sub>POLIC</sub>	L <sub>HEALTH</sub>	L <sub>KNOW</sub>	SUM	THEN HUMS	
1	B	0.0634	B	0.847	B	0.273	2	1	1	4	B	0.0147
2	B	0.0634	B	0.847	A	0.509	2	1	2	5	B	0.0273
3	B	0.0634	B	0.847	G	0.218	2	1	3	6	B	0.0117
4	B	0.0634	A	0.148	B	0.273	2	2	1	5	B	0.00256
5	B	0.0634	A	0.148	A	0.509	2	2	2	6	B	0.00477
6	B	0.0634	A	0.148	G	0.218	2	2	3	7	B	0.00204
7	B	0.0634	G	0.00487	B	0.273	2	3	1	6	B	0.0000842
8	B	0.0634	G	0.00487	A	0.509	2	3	2	7	B	0.000157
9	B	0.0634	G	0.00487	G	0.218	2	3	3	8	A	0.0000672
10	A	0.533	B	0.847	B	0.273	4	1	1	6	B	0.123
11	A	0.533	B	0.847	A	0.509	4	1	2	7	B	0.230
12	A	0.533	B	0.847	G	0.218	4	1	3	8	A	0.0985
13	A	0.533	A	0.148	B	0.273	4	2	1	7	B	0.0215
14	A	0.533	A	0.148	A	0.509	4	2	2	8	A	0.0401
15	A	0.533	A	0.148	G	0.218	4	2	3	9	A	0.0172
16	A	0.533	G	0.00487	B	0.273	4	3	1	8	A	0.000708
17	A	0.533	G	0.00487	A	0.509	4	3	2	9	A	0.00132
18	A	0.533	G	0.00487	G	0.218	4	3	3	10	A	0.000566
19	G	0.403	B	0.847	B	0.273	6	1	1	8	A	0.0933
20	G	0.403	B	0.847	A	0.509	6	1	2	9	A	0.174
21	G	0.403	B	0.847	G	0.218	6	1	3	10	A	0.0745
22	G	0.403	A	0.148	B	0.273	6	2	1	9	A	0.0163

23	G	0.403	A	0.148	A	0.509	6	2	2	10	A	0.0303
24	G	0.403	A	0.148	G	0.218	6	2	3	11	A	0.0130
25	G	0.403	G	0.00487	B	0.273	6	3	1	10	A	0.000536
26	G	0.403	G	0.00487	A	0.509	6	3	2	11	A	0.000999
27	G	0.403	G	0.00487	G	0.218	6	3	3	12	G	0.000428

Appendix 11. Fired rule base for WEALTH

Rule #	IF PR is		and ST is		and RE is		L <sub>PR</sub>	L <sub>ST</sub>	L <sub>RE</sub>	SUM	THEN WEALTH	
1	A	0.161	B	0.296	B	0.285	2	1	1	4	B	0.0136
2	A	0.161	B	0.296	A	0.511	2	1	2	5	B	0.0244
3	A	0.161	B	0.296	G	0.204	2	1	3	6	A	0.00976
4	A	0.161	A	0.511	B	0.285	2	2	1	5	B	0.0235
5	A	0.161	A	0.511	A	0.511	2	2	2	6	A	0.0421
6	A	0.161	A	0.511	G	0.204	2	2	3	7	A	0.0168
7	A	0.161	G	0.193	B	0.285	2	3	1	6	A	0.00891
8	A	0.161	G	0.193	A	0.511	2	3	2	7	A	0.0159
9	A	0.161	G	0.193	G	0.204	2	3	3	8	A	0.00637
10	G	0.839	B	0.296	B	0.285	3	1	1	5	B	0.0708
11	G	0.839	B	0.296	A	0.511	3	1	2	6	A	0.127
12	G	0.839	B	0.296	G	0.204	3	1	3	7	A	0.0507
13	G	0.839	A	0.511	B	0.285	3	2	1	6	A	0.122
14	G	0.839	A	0.511	A	0.511	3	2	2	7	A	0.219
15	G	0.839	A	0.511	G	0.204	3	2	3	8	A	0.0874
16	G	0.839	G	0.193	B	0.285	3	3	1	7	A	0.0462

17	G	0.839	G	0.193	A	0.511	3	3	2	8	A	0.0828
18	G	0.839	G	0.193	G	0.204	3	3	3	9	G	0.0331

Appendix 12. Sensitivity analysis spreadsheet

Indicator index	$x_c$	-10%	+10%	-10%	+10%	-10%	+10%	-10%	+10%
		$x_c + \delta$		$OSUS(x_c + \delta)$		$\Delta_c$		$ D_c $	
1	0.946	0.851	1.00	0.437	0.459	-0.0138	0.00792	0.000749	0.000429
2	0.964	0.867	1.00	0.436	0.457	-0.0150	0.00566	0.000545	0.000205
3	0.978	0.880	1.00	0.435	0.455	-0.0158	0.00363	0.000355	0.0000814
4	0.969	0.872	1.00	0.445	0.453	-0.00609	0.00198	0.000191	0.0000620
5	0.635	0.572	0.699	0.450	0.453	-0.00170	0.00170	0.000622	0.000622
6	0.375	0.337	0.412	0.450	0.453	-0.00160	0.00160	0.00100	0.00100
7	0.799	0.719	0.879	0.440	0.462	-0.0110	0.0110	0.00221	0.00221
8	0.0148	0.0133	0.0162	0.451	0.451	-0.0000871	0.0000871	0.0000858	0.0000858
9	0.772	0.695	0.850	0.441	0.462	-0.0103	0.0108	0.00235	0.00247
10	0.320	0.288	0.352	0.448	0.455	-0.00375	0.00375	0.00255	0.00255
11	0.965	0.869	1.00	0.432	0.458	-0.0194	0.00703	0.000679	0.000246
12	0.587	0.528	0.646	0.448	0.455	-0.00352	0.00352	0.00146	0.00146
13	1.00	0.900	1.00	0.437	0.451	-0.0143	0.000	0.000	0.000
14	0.252	0.227	0.277	0.450	0.452	-0.00119	0.00119	0.000893	0.000893
15	0.861	0.775	0.947	0.441	0.461	-0.0102	0.0102	0.00141	0.00141
16	0.863	0.777	0.949	0.441	0.462	-0.0103	0.0103	0.00141	0.00141
17	0.263	0.237	0.289	0.450	0.453	-0.00125	0.00125	0.000918	0.000918
18	0.115	0.104	0.127	0.451	0.452	-0.000433	0.000433	0.000383	0.000383
19	0.930	0.837	1.00	0.449	0.453	-0.00207	0.00155	0.000144	0.000108

20	0.712	0.640	0.783	0.449	0.458	-0.00191	0.00639	0.000550	0.00184
21	0.280	0.252	0.308	0.450	0.453	-0.00142	0.00142	0.00102	0.00102
22	0.864	0.777	0.950	0.443	0.460	-0.00823	0.00823	0.00112	0.00112

Colab link: [ChE447Project.ipynb](#)

Google sheet: [ChE447\\_Project\\_data](#)



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