CIRCULAR ECONOMY CALCULATOR

A Thesis

by

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MASTER OF SCIENCE

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ABSTRACT

The world has limited natural resources that are being depleted. Increasing landfill wastes and higher levels of pollutants can lead to environmental crises, such as climate change. Circular Economy (C.E.) concept can be one of the approaches to solve this issue. According to Ellen Macarthur foundation, "Circular Economy is based on the principles of designing out waste and pollution, keeping products and materials in use, and regenerating natural systems. C.E. looks beyond the current take-make-waste extractive industrial model." There is a current lack of literature in the methods to measure and assessing C.E., especially C.E. on the company-level.

This work explores the measurement of the company-level Circular Economy (C.E.). Measuring C.E. help practitioners and policymakers to assess their company's C.E., which will help them acknowledge the areas that require more improvement in terms of circularity. A variety of C.E. indicators and metrics will be discussed, and C.E. indicators that cover the goals of C.E. will be selected. A toolbox is developed can assess the circularity on a company level. The toolbox is built on a website that will be publicly available to be used by all companies in different sectors. The results of the assessment will allow a comparison between the companies in the same sector. The developed toolbox presents the results in visual graphic plots and calculate the holistic Circular Economy metric index.

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Contributors

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All the work conducted for the thesis was completed by the student independently.

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1. INTRODUCTION

The current world has limited natural resources, and the current human behavior is leading to natural resource depletion. It is also causing severe environmental problems such as water, air, and soil pollution. The need to transition to more sustainable behavior is gaining momentum in the academia and industry. Circular Economy (C.E.) is one of the approaches that is being proposed as a solution to this issue [1].

1.1. Problem statement

The current global economic model uses a linear flow of materials and energy (Fig 1), that is, materials are extracted from a source, used in production then dumped. This current linear system can result in natural resource depletion, resulting in an unsustainable system. C.E. suggests a circular flow of material and energy (energy circularity mean the utilization of lower temperature and pressure levels of energy in cascade), which will result in a more sustainable economic system [2].

European Union (E.U.) has a 2050 vision of 'living well within the limits of the planet'. A part of moving toward this goal includes a Circular Economy action plan that was published in 2015 to assist in the transition toward C.E. in the E.U. Since 2015, monitoring the current C.E. indicators showed that the E.U. achieved some progress toward C.E., mainly in material resources efficiency and waste management. Recycling rates were increased, when waste generated from manufacturing and services dramatically decreased. However, some of the challenges include the difficulty of measuring some of the C.E. indicators such as eco-design, reuse, sharing economy, and social indicators [3].

1.2. Objective

The objective is to develop a toolbox that can assess the circularity of a company. This will help companies of different sectors to assess their transition toward C.E. quantitatively, which will possibly contribute to the transition toward C.E. in the industrial sector. This toolbox will be based on the use of indicators that can measure holistically the convergence towards C.E. The results will be presented in both a graphical representation and in an index-metric number to allow the comparison between companies in the same sector or company improvement from year to year.

2. LITERATURE REVIEW

2.1. Circular Economy

2.1.1. Circular Economy Definition

There is no current universal definition for circular economy [2]. Many researchers suggest that circular economy and sustainable development should contribute to the following three dimensions i) economic ii) environmental and iii) social levels. This is done by maximizing the use of material and energy that enters the economic system, through cyclical material use, energy cascade, and reduce the use of natural resources. One of the ways to narrow the possible definitions of circular economy to one universal definition is by defining a method to measure circular economy [2]. (Fig. 1) shows the difference between linear economy and circular economy.

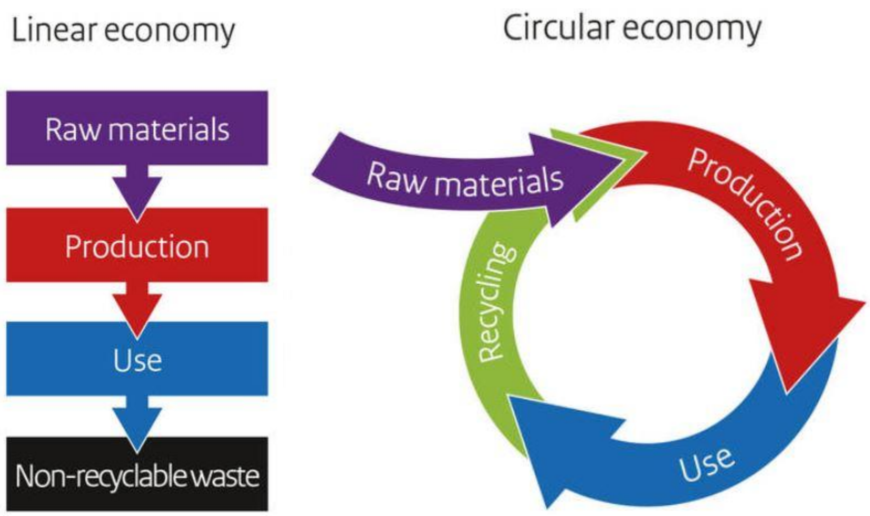


Figure 1: Linear Economy (left) vs Circular Economy (right). Resources and energy are maximized in time and value in the circular economy flow system [2]. (Image source: Government of Netherland Website [18]).

2.2. Measuring C.E.

2.2.1. Benefits of Measuring C.E.

Measuring C.E. can help in evaluating the contribution of C.E. principles toward sustainability. It is also necessary for policymakers to assess the effect of C.E. on the market, which will help them acknowledge the areas that need more resources and time on improving their circularity. Measuring C.E. also helps to compare the circularity of companies, products, supply chains, and countries. This will result in the acceleration of the transition toward C.E. [5].

2.2.2. Sustainability Report strengthens and weaknesses

Many companies publish an annual sustainability report. Many goals that have been developed for the sustainability report can be used for C.E., however, circular economy is a much broader concept than sustainability. Sustainability reports usually focus on waste and water recycling, CO_2 emission, and the intensity of resources used [7]. However, C.E. covers a more holistic view of the economic system. More data should be reported to assess the circularity of an entity. For example, C.E. should also consider the level of toxicity of the output materials and product durability are significant factors that are involved in the assessment of C.E. as they have a significant effect on the surrounding environment, economics, and social concern [8].

2.2.3. Current Limitations in Reporting and Measuring C.E.

Research on C.E. has been spreading in the last few years, yet the methods for C.E. assessment are still not widely available, especially measuring circularity on micro-level (company or product level) [4]. Most companies do not release or even measure many factors that are used to assess the circularity of an entity. A unified C.E. standard will help companies in applying C.E. concepts [7].

2.2.4. Circular economy Indicators

The terms "Indicators" and "Metrics" are sometimes used interchangeably in many C.E. papers. These two words are used in different specific meanings in this research paper. The term "Indicator" will represent a particular measurement assessment of a quantitative value that the company provides (e.g., Water Consumption or Renewable Energy input). The term "Metric" is used to describe a holistic final evaluation of circular economy using several C.E. indicators. The C.E. metric value is between 0 and 1 and represents the transition from linearity to the circularity of that company.

Developing C.E. indicators will help summarize the performance of the complex dynamic systems [5]. The complexity of the topic of C.E. indicators comes from not having standard indicators that are used worldwide to measure Circular Economy. In this paper, only C.E. indicators that are used on Micro-level C.E. (Product level and Company Level) will be discussed.

Below, two research papers will be presented suggesting different approaches to measure product level C.E. with corresponding indicators followed by the discussion on C.E. implementation scale levels to differentiate between the product and company level circularity. Then a discussion on the five goals of C.E. will be presented and finally the C.E. indicators that will be used in this paper toolbox.

2.2.4.1. Measuring C.E. on product-level: Approach 1

According to Elia (2016)[4], Circular Economy indicators should cover four main category parameters; i) Material Flow, ii) Energy Flow, iii) Land use & consumption, and iv) other life-cycle based. These four categories are measured using index-based method typology, either using a "single indicator" or "multiple indicators", which is the average of several single indicators [6].

The Proposed taxonomy of index-based methodology by Elia (2016)[4] are summarized in (Table 1).

According to Moraga (2019)[13], C.E. indicators should cover six main strategies; the first five strategies focusing on preserving i) the **Function** of the product through sharing platforms and multifunctionality, ii) the **Product** itself through increasing durability and reuse, iii) Preserve the product **components** through the recovery of parts**, iv)** the **materials** through recycling, v) the **embodied energy** through energy recovery. The last strategy (vi) is the **reference scenario,** which is measuring linear economy compared to circular economy.

Table 1: The proposed taxonomy of index-based methodologies.

Parameter \ type	**Single Indicators**	**Multiple Indicators**
Material flow	1. Water Footprint 2. Material Input per Unit of Service 3. Ecological Rucksack	1.Material Flow Analysis 2. Substance Flow Analysis
Energy Glow	1. Cumulative Energy Demand 2. Embodied Energy 3. Energy Analysis 4. Exergy Analysis	
Land use & consumption	1. Ecological Footprint 2. Sustainable Process Index 3. Dissipation Area Index	
Other life cycle based	1. Carbon Footprint 2. Ecosystem Damage Potential	1. Life Cycle Assessment 2. Environmental Performance Strategy Map 3. Sustainable Environmental Performance Indicator

2.2.4.2. Measuring C.E. on product-level: Approach 2

During this work, C.E. is divided into steps according to their Life Cycle Thinking (LCT) approach. LCT is to consider the life cycle of the product, such as design, production, consumption, use, and disposal.

These six strategies should be covered by three different types of indicators measurement known as the scopes. The scopes are divided according to their life cycle thinking (LCT)

i) Scope 0 measure the physical properties of the cycle without their LCT approach.
ii) Scope 1 measure the physical properties while considering the LCT approach, such as reusability/recyclability/recoverability/reuse indicators and the materials are recycled, and energy is recovered.
iii) Scope 2 measure the effect of the technological cycles affecting the environment, economics, and social concern. These three scopes are summarized in (Fig. 2).

Table 2 summarizes Moraga's (2019)[13] proposed indicators for the micro-scale. Some of the indicators are only valid for product-level C.E. not company level C.E.

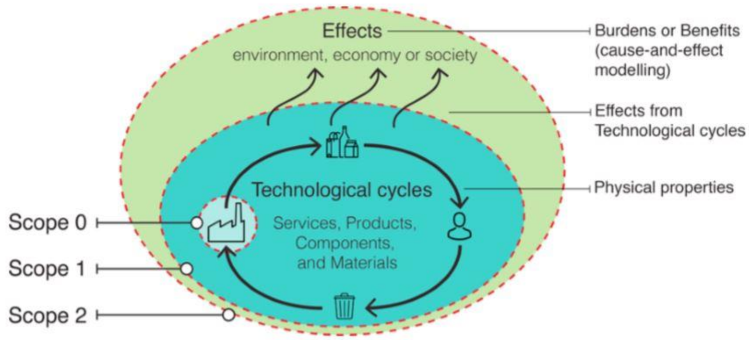


Figure 2: The three different scopes levels for the indicator categories.

Table 2: Suggested indicators for the six C.E. strategies based on the LCT scope level.

C.E. Strategy	Scope 0	Scope 1	Scope 2
Function	Sharing platforms, product reuse		
Product	-Ease of disassembly (eDIM)	-TRP -Longevity -Material Circularity Indicators (MCI)	-Eco-cost value ration (EVR) -Product level Circularity Metric (PLCM) - Sustainable Circular Index (SCI)
Component	-Ease of disassembly (eDIM)	-Total Restored Products (TRP)	- Product level Circularity Metric (PLCM)
Material	-Old scrap collection rate (C.R.) -Recycling Input rate (RIR) -Recycling process efficiency Rate (R.R.)] -Old Scrap Ratio (OSR) -End of life Recycling rate (EOL-RR)	-Number of Times of Use of Material (NTUM) -Material Circularity Indicators (CIRC) -Longevity -Lifetime of Materials on Anthroposphere (LMMA) - Material Circularity Indicators (MCI)	- Product level Circularity Metric (PLCM) -Circular Economy Index (CEI) -Sustainable Circular Index (SCI) -Circular Economy Performance Indicators (CPI) -Global Recourses Indicators (GRI) -Value-Based Recourses Efficiency (VRE) -Displacement

Table 2 continued.

C.E. Strategy	Scope 0	Scope 1	Scope 2
Embodied Energy		- Material Circularity Indicators (MCI)	- Circular Economy Performance Indicators (CPI) -Sustainable Circular Index (SCI)
Reference		- Material Circularity Indicators (MCI) -Longevity	-Sustainable Circular Index (SCI)

2.2.4.3. Circular Economy implementation scales

Circular Economy implementations include three scales; i) Micro-level for a single product, consumer or company, ii) Meso-level for eco-industrial parks, iii) and Macro-level is for a city, region, or country. Micro-scale C.E. includes product level or company level circularity; it forms some confusion as not all the methods or indicators are valid for both company and product. It is suggested that there should be a distinction between the product and company levels. A new C.E. level scale term is suggested to be used called "nano-scale" C.E. describing product circularity. This will result in four C.E. scale levels, where the micro-level being used only for company level, and nano-level used for a product. Following such an approach, C.E. indicators can be distinguished whether they are being used for the company or product level circularity [13]. The two papers discussed the proposed C.E. indicators for the micro-level and with the focus one the product level. No paper article was found to specifically discuss the indicators to be used on a company level alone. The indicators that will be used in this project benefit from i) the current product-level indicators, ii) the sustainability report indicators, and iii) suggested indicators that companies should start reporting.

2.2.4.4. Circular Economy characteristics and goals

The goals of C.E. are summarized in 5 characteristics [3][8] are listed below:

i) Reduction of material losses/residuals: Waste and pollutant minimization.
ii) Reduction of input and use of natural resources: Reduction of use of natural resources such as water, land, and raw material.
iii) Increase in the share of renewable resources and energy: Replacing non-renewable energy and material with renewable ones.
iv) Reduction of emission levels: Reduction of emission and pollutants.
v) Increase the value durability of products: Increase product lifetime.

In this paper, these five C.E. characteristics are used as an evaluation reference with a slight alteration in the naming and categorizing order. Characteristic 2 and 3 are changed in this paper into Energy input and Resources input for simplicity. The water input and output are part of the resources in the above goals; however, in this paper water input and output is separated into a sixth category as they have their unique indicators. The six characteristics are summarized in (Fig. 3)

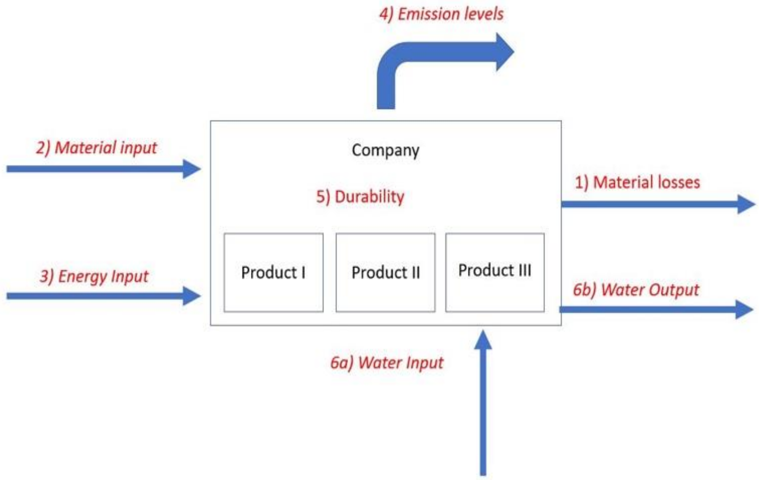


Figure 3: The goals and characteristics of C.E. measurement.

2.2.4.5. Indicators used in this paper toolbox

Most of the indicators used in this research paper are cited from the (GRI sustainability reporting standards 2018) report [15]. The report contains a list of suggested universal standards to be used in the sustainability reports of several topics including Economic, Environmental and Social. Although the C.E. concept definition includes the Economic and Social impacts [8], however, the environmental indicators are more related to the 5 C.E. goals and characteristics.

The Environmental Topic in the GRI report includes 8 categories: i) Materials, ii) Energy, iii) Water and Effluents, iv) Biodiversity, v) Emissions, vi) Effluent and Waste, vii) Environmental compliance, and viii) Supplier Environmental Assessment. The GRI report indicators will cover the five C.E. goals as follows:

The (GRI material section) will cover the indicators from the (material input) C.E. goal as well as (material losses) goal. The (GRI Energy section) will cover the energy input goals, both renewable and nonrenewable sources. The (GRI Emission section) will cover the (Emission levels) C.E. goal about the CO_2 equivalent emissions indicator. The (GRI Water and Effluents section) covers the (water input and output) C.E. goal. The (GRI Effluents and Wastes section) covers the part of the (Material losses) C.E. goal. However, the GRI report also does not consider recycling effectiveness of the different disposed material, therefore, the EPA materials list [15] is used to determine the disposed materials recycling and recovering effectiveness.

The C.E. goal of durability is not an element in the sustainability report, the durability indicators are one of the indicators that it is recommended for the companies to submit in their annual C.E. report.

2.2.5. Circular Economy Metric

While there are several methods to measure Circular Economy different characteristics or stages, there is a lack of quantitative index assessing the holistic circular economy metric. This approach was proposed by Avraamidou (2018)[14] to assess Food-Energy-Water Nexus (FEW-N) in a singular quantitative index. This method can be applied to circular economy because of the similarity between C.E. and FEW-N in their indexes methods.

The simple metric to assess circular economy is to use the **linear average,** which is multiplying each C.E. characteristic with its corresponding weight and dividing it by the sum of weights, this method does not require scoring a high index in each C.E. characteristic, lower quantities in some categories will be neutralized by the other high quantities.

Higher-order averages is an alternative method to calculate a C.E. metric. Higher-order averages can be calculated using the following equation (Eq.1):

$$r^{th} \text{ order average} = \text{Sum of all } r^{th} \text{ order multiplicative combinations of decision indexes} / C_r^n \quad \text{(Eq.1)}$$

Where $\mathbf{C_r^n}$ is the total number of possible $\mathbf{r^{th}}$ order combinations of n decision indexes.

This method will raise the power of the weighting factor, meaning that the indexes with lower value would have a higher effect on the total C.E. metric value. A **bilinear average** (B.A.) and a **trilinear average** (T.A.) will also be used to assess the holistic C.E. metric value.

2.3. Development of a toolbox

2.3.1. What is a toolbox?

A C.E. toolbox is used to measure the circularity of an entity by inserting the reported data of that year into the toolbox showing the strengths and weaknesses of each characteristic.

2.3.2. Currently available C.E. toolboxes

The presence of C.E. metrics is not very popular, the first C.E. was introduced in 2015, and currently, there are three C.E. toolboxes. The three metrics are analyzed, the function and advantages and disadvantages of each were studied, the table below summarizes the findings.

Table 3: Current existing C.E. toolboxes comparison.

Description	**Circular Economy Toolkit (CET) [10]**	**Material Circular Indicator (MCI) [11]**	**Circular Economy Indicator Prototype (CEIP) [12]**
Level	Product Circularity	Product-Company Circularity.	Product circularity
Use Input type	Trinary based Bar slider	Mass and Percentages Numerical Data	Point-Based including 12 Yes or no Questions and three Percentage Numerical Data

Table 3 continued.

Description	**Circular Economy Toolkit (CET) [10]**	**Material Circular Indicator (MCI) [11]**	**Circular Economy Indicator Prototype (CEIP) [12]**
Input Categories	7 Categories i- Design, Manufacture, and Distribute. ii- Usage (by the customer). iii- Repair/Maintenance iv- Reuse/Redistribution v-Remanufacturing/ Refurbishment vi-Products as a Service. vii- Product Recycling at end of life.	Information about Each material used: i-Material Name ii-Material Mass (Kg) iii-Recycled Feedstock iv-Recycled Efficacy. v-lifespan compared to industry vi-Functional Unit compared to the industry. vii-Complementary indicator: A list of Materials, and the corresponding total mass/revenue of each product.	Five Life Cycle Stages of a product: i-Design/Redesign. ii- Manufacturing. iii-commercialization iv- In Use. v-End of Use.
Output type	Shows the improvement potential of each of the 7 categories as: (High-Medium-Low).	MCI of each product between 0 and 1 (1 is the highest). Also, the Total MCI of the company using the ratio of each product MCI.	i-Score Rating Percentage % of each of the 5 Lifecycle stages. ii-The total product C.E. rating. iii-The Spider-plot diagram of each lifecycle stage.
Interface	Webpage	Excel	Excel
Notes	Slider input is not an accurate assessment of the company's data. People tend to put the slider in the middle. [9]	C.E. concept is broader than the MCI average. Energy used and environmental impact should be included	Binary questions are not an accurate assessment of C.E.

2.3.3.Current C.E. Toolboxes limitations

All the three C.E. Toolboxes are easy to use and can be completed in between 5-15 minutes once all the data are available. The decision-makers can have a quick assessment of where their product stands in C.E.

According to EMF, their MCI tool is based on that the hypothesis that the Circularity on the Company-Level is the average MCI of each product (Taking the mass or revenue as a normalization factor), and the MCI of each product is the average of the MCI of each material in that product [11]. This hypothesis narrows down the concept of C.E. to just the mass flow analysis, not considering the broader C.E. definition [9].

Circular Economy Toolkit (CET) is easy and fast to use, but it is not a lot of numerical report data is used, and hence, the outcome is not an accurate estimation of C.E., because it leaves the (High-Medium-Low) estimation to the user without a numerical reference.

Circular Economy Indicator Prototype (CEIP) is also simple and easy to use, as the user does not need access to the company's information to fill the tool questionnaire., but the Binary questions do not cover the complexity of C.E. And it is less accurate to compare between different product's C.E. using simple

Yes/No question. All the three tools are used mainly to assess product circularity (except for MCI). No existing tool is currently available that specializes in Company-level circularity.

3. METHODOLOGY

3.1. Indicators explanation and sources

The purpose of this project is to develop a new way to assess the circular economy for companies and manufacturers. Different indicators from the sustainability report and different C.E. projects were selected to develop a toolbox that its function is to measure the circularity of the company

Table 4 shows the main six C.E. characteristics with the proposed indicators to evaluate each C.E. character

Table 4: Proposed C.E. Characteristics and Indicators

C.E. characteristics	**C.E. indicators**	**Subcategory**
1) Energy	1) Non-Renewable Energy used [15]	
	2) Renewable Energy used [15]	
	3) Non-renewable Energy produced	
	4) Renewable energy produced	
2) Durability	1) The average Products lifetime (Use the mass percentage of all products)	
	2) Infrastructure lifetime (years)	
3) Emission levels	1) CO_2 emission (ton) (equivalent) [15]	
	2) SOx, Nox or VOC's (tonnes)	
	3) CO_2 offset	
4) Water Input and output	1) Water Consumption [15]	
	2) Water disposal [15]	
	3) Water discharge	1) Fresh Water 2) Other Water
5) Material input	1) Non-renewable material (kg) [15]	
	2) Renewable material used (kg) [15]	
6) Material losses (output)	1) Mass of material to landfill (disposal) (kg) [15]	
	2) Toxic Material [19]	
	3) Mass of material recycled (kg) [16]	i-Paper and paperboard ii-Glass iii-Metals iv-Steel v-Aluminum vi-Other nonferrous metals vii-Plastics viii-Rubber and leather ix-Textiles x-Wood xi-Food and organic materials xii- Other Materials

Each of the six characteristics will have an index outcome from 0 to 1, the Liner and a higher-order average of the indexes will be used to generate a holistic C.E. metric.

Some Indicators were changed specifically for each specific industry, For the Automotive industry, an indicator of "Average MPG of all vehicles produced (Mile per gallon equivalent)" was added under the emissions characteristic, this indicator is highly used by The Corporate Average Fuel Economy (CAFE) standards are regulations in the United States [29]. For the Manufacturing and Technology Industry, an indicator for the End of life of the products was added under the durability, which is the "Percentage of mass recycled/reuse of total mass of products total mass" after the end of life of the products. This indicator is significant to the overall circularity of the materials. As there is no product produced in the financial and Services industry, an alternative indicator was added to the durability characteristic, which is "Percentage area of all buildings that have a LEED (Leadership in Energy and Environmental Design) certificate, which is internationally recognized green building certification given by a third party organization (U.S. Green Building Council) to measure the sustainability of a certain building, which will reflect the durability of a specific building.

The methodology that will be followed for the development of the C.E. toolbox is divided into four steps:

a) <u>Selecting indicators:</u> Indicators are chosen to cover the six characteristics of C.E. Most of the indicators are chosen from the GRI Sustainability Reporting Standards, many companies use these standards for their annual sustainability reports. The sustainability indicators cover a part of the broad C.E. concept; several other C.E. indicators are introduced that are suggested for the companies to start reporting. Each company will input the indicators according to its industrial sector.
b) <u>Measuring for different sectors:</u> Requirements for measuring C.E. vary between Industrial sectors, for example, if the indicator of measuring the "embodied energy" is selected (the total energy consumed to produce a product unit). This indicator can be used to measure the embodied energy for a car manufacturer, the embodied energy can be defined by each car unit, however, the concept of embodied energy is not applicable for the oil and gas industry, an alternative indicator can be used such as energy needed to produce 1 gallon of oil. The toolbox created should have an option to adapt for different industrial applications. The toolbox will also have the option to input the indicators in both the imperial and the metric unit systems.
c) <u>Calculation and visualization:</u> Each input indicator will be normalized on the scale of 0 – 1 using the minimum to maximum approach. The minimum and maximum are determined for the current industry values, data will be collected to determine the industry's existing range of values for each indicator is used in the toolbox, and hence "input data point" will be normalized to produce a value between 0 and 1 (Fig. 4). The plot represents the C.E. evaluation of a specific company; this plot will allow the company to compare their result to the average results of all the other companies that used this toolbox in their industrial sector. In the example above, "Company 1" will acknowledge that their circularity in

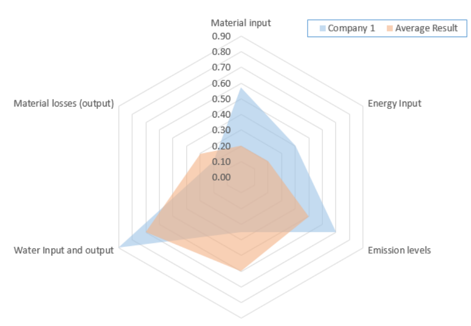


Figure 4: A spider-plot for the six characteristics scaled from 0 – 1

most of the categories is more than the sector average level. However, they will need to spend more resources and time on improving their circularity in the "Material losses" and "Durability" characteristics. The report results will also include the liner and higher-order averages for a holistic C.E. metric value, a single quantitative value as a percentage out of 100 for the entire company circularity.

d) Web-based calculator: The toolbox will be available on a website that can be accessible to everyone, the website will be easy to use and can be filled in under 5 minutes once all the company's data are available.

3.2. How the Calculators works

An important feature of this calculator is to calculate the C.E. metric and indicators relative to the company's own data. For example, to evaluate the companies' consumption of renewable energy. One way is to compare the company's consumption of renewable energy compared to other company's renewable energy consumption. This method will not take into account the size of the company and its overall energy consumption. Also, a large set of data should be collected to determine the upper and lower limits for this comparison accurately. The other method that will be used in most of this report testing, except for the durability and emissions, is to calculate the metrics relative to the company's own result. Most indicators are calculated using a percentage; for example, "Renewable Energy used" divided over "Total Energy used" will give a number between 0 and 1 to evaluate the renewable energy indicator.

In this section, the reported value that the company will input will be donated as Input (I) next to the value. The calculations for the C.E. metric is divided into two steps. First, the company data will be inserted into the indicators' value, which will be used to calculate a normalized value between 0 and 1 for each of the six characteristics indexes. The second step is to use the result of all the six characteristics indexes to calculate the C.E. Metric using a Bi-linear average, as shown in Fig. 5.

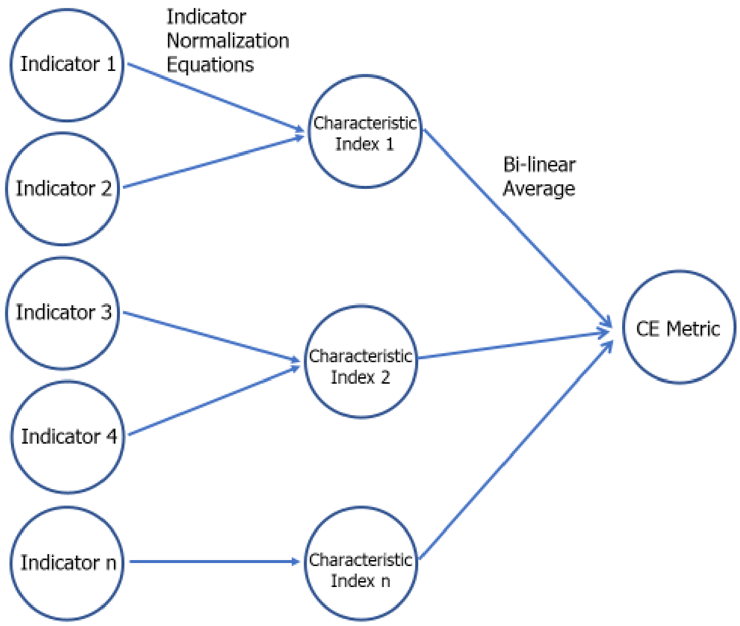


Figure 5: The two steps to calculate the C.E. Metric.

Each one of the 6 Characteristics indicators is shown below:

a) Energy Input

The Energy input is calculated using the average of both "Energy Produced" & "Energy Consumed" using the following equation:

I. $$Energy\ Consumed\ indicator = \frac{Renewable\ Energy\ consumed\ (I)}{NonRenewable\ Energy\ consumed\ (I) + NonRenewable\ Energy\ consumed (I)} \quad (2)$$

II. $$Energy\ Produced\ indicator = \frac{Renewable\ Energy\ Produced\ (I)}{NonRenewable\ Energy\ Produced\ (I) + NonRenewable\ Energy\ Produced\ (I)} \quad (3)$$

Each equation will result in a value between 0 and 1, and the linear average is used to calculate the "Energy Input" Normalized Index:

III. $$Energy\ Input\ Index = \frac{Energy\ Consumed\ indicator + Energy\ Produced\ indicator}{2} \quad (4)$$

The Result for the "Energy input Indicator" will be the first of six values that will be used to calculate the final Circular Economy Metric.

b) Durability

Three C.E. indicators will be used to estimate the Durability. It is not very common for companies to report these indicators. Therefore, each one of these indicators will have a conditional question as: "Do you have the information for your company average product lifetime." If the answer is no, the value of this indicator will not be calculated in the final durability index value.

The three indicators will result in three normalized values (0 to 1) that are calculated as the following:

I. $$Product\ lifetime\ indicator = \frac{Average\ product\ Lifetime\ (I) - Minimum\ lifetime\ value}{Maximum\ lifetime\ value - Minimum\ lifetime\ value} \quad (5)$$

Where;

Average Product Lifetime: of all the products in that company.

Maximum lifetime value: It depends on the industry. For the manufacturing and technology, the Maximum was assumed to be six years [20]. More data should be collected to determine the limits. Minimum lifetime value: zero years.

II. $$Infrastructure\ lifetime\ Indicator = \frac{Infrastructure\ Lifetime\ (I) - Minimum\ lifetime\ value}{Maximum\ lifetime\ value - Minimum\ lifetime\ value} \quad (6)$$

Where;

Maximum and Minimum lifetime value: Average values depend on the industry [21]. More data should be collected to determine the limits.

III. End of Life (For all Products)

End of life is the percentage of the product mass recycled and reused over its total mass of products total mass (%). End of life indicator is only included in the industries that produce a physical product output. It is recommended that companies report this value as a single value as a Percentage, It will be used in the following equation;

$$End\ of\ life\ Indicator = \frac{End\ of\ life\ recycled\ or\ reused\ (I)}{50\%} \quad (7)$$

Reporting the end of life recycling and reuse value is not always common in all industries. The value of 50% is an arbitrary random that is used instead of 100%. This will result in a more reasonable final durability index. Each equation will result in a value between 0 and 1, and the linear average is used to calculate the "Durability" Normalized Index:

$$Energy\ Input\ Index = \frac{Product\ lifetime\ indicator + Infrastructure\ lifetime\ Indicator + End\ of\ life\ Indicator}{n}$$
(8)

Where n = 1,2 or 3. Depend on the number of durability indicators that are used as an input in the calculator.

The Result for the "Durability Indicator" will be one of six values that will be used to calculate the final Circular Economy Metric.

c) Emission levels

The amount of Gasses emissions, including Greenhouse gasses (GHG) and Acidic gasses, will directly affect the environment. The more gasses are emissions. More damage is done to the environment. Therefore, this indicator is calculated regardless of the company size. The emissions indicators will be calculated compared to other companies.

I. $$GHG\ emissions\ indicator = \frac{Total\ GHG\ emissions\ (I) - CO2\ offset\ projects\ (I)}{Upper\ limit\ value} \quad (9)$$

Where;

Upper limit value depends on the industry, for the oil and gas industry calculator, the value is taken from the highest company emissions in the U.S. [22], where for the industries it was taken from the 20th highest emissions company between all companies. This will result in a more distinct relative comparison between different companies.

II. $$Acidic\ Gasses\ Indicator = \frac{Total\ Acidic\ Gasses\ emission\ (I)}{Upper\ limit\ value} \quad (10)$$

Where; the upper limit is taken from the limits of the same companies ranking for GHG emissions.

$$Emissions\ Level\ Index = \frac{GHG\ emissions\ indicator + \ Acidic\ Gasses\ Indicator}{2}$$

The Result for the "Emissions Level Index" will be one of six values that will be used to calculate the final Circular Economy Metric.

d) Water Input and output

Three C.E. indicators will be used to evaluate the "water input and output index" characteristics. Which will evaluate the total water consumption, percentage of water recycled, and freshness of the water discharged. The three equations are as follows:

Note that: Total Water Withdrawal = Total Water Consumption + Total Water discharge

I. $$Water\ Consumption\ indicator = \frac{Water\ consumption\ (I)}{Water\ Consumption\ (I) + Water\ discharged\ (I)} \quad (11)$$

Many companies only report the "water consumption" value, which disregards the amount of water withdrawn. The "Water Consumption Indicator" is calculated as a percentage of the total water withdrawn to consider the efficiency of using the water and the size of the company.

II. Water Recycled Percentage Indicator (I)

This indicator considers the amount of water recycled from the total discharged water. Companies should report this number as a percentage, and it will be used directly as an index from 0 to 1 value.

III. $$Fresh\ Water\ Indicator = \frac{Fresh\ Water\ Discharge\ (I)}{Fresh\ Water\ Discharge\ (I) + Other\ Water\ Discharge\ (I)} \quad (12)$$

This Indicator will evaluate what percentage of the water that goes back to nature is freshwater; the "other water" is water that contains a higher percentage of impurities. Note that the Total Water discharge = Fresh Water Discharge + Other Water Discharge.

$$Water\ Input\ and\ Output\ Index = \frac{Water\ Consumption\ indicator + Water\ Recycled\ Indicator + Fresh\ Water\ Recycled\ Indicator}{3} \quad (13)$$

The Result for the "Water Input and Output Index" will be one of six values that will be used to calculate the final Circular Economy Metric.

e) Material Input

One indicator only used to calculate the Material input. The Material Input Index is directly calculated using the percentage of renewable material sources used. It is not common for companies to report these numbers. However, they are critical for a full cycle for C.E.

$$Renewable\ Material\ Input\ Indicator = \frac{Renewable\ Material\ Used\ (I)}{Renewable\ Material\ Used\ (I) + Nonrenewable\ Material\ Used\ (I)} \quad (14)$$

The Renewable Material Input Indicator equal to the Material input index. The Result for the "Material Input index" will be one of six values that will be used to calculate the final Circular Economy Metric.

f) Material Loss (Output)

There are three indicators to evaluate the "Material output" index, which are Diversion Rate Percentage, Hazardous Material Recovered Percentage, and the Material Recycled Quality. The first two are straightforward values that the company can report. The indicators are as follows:

I. Diversion Rate Percentage Indicator (I)

Diversion rate is the total Recycled and Other diversions over the Total waste, most companies provide the diversion rate in their environmental report.

II. Hazardous Waste Recovered Percentage (I)

Hazardous Waste Recovered Percentage, which is the total hazardous material that was recovered before releasing over the total hazardous material produced, some companies provide the hazardous material as a mass in Kilograms or Pounds, however, this does not show the effort done by the company to recover their output. Other companies already provide the Hazardous Waste Recovered Percentage in their environmental report.

III. Recycling Quality of Material Output

There is no unified method to determine the quality of material recycled. Therefore, the industry market data will be used to find how common it is to recycle a specific material [23]. For example, 66% of all the Paper and Paperboard material generated is recycled in the U.S., while only 27% of all the Glass that is generated is being recycled. Therefore, it might be preferable to use the material that is being recycled more. This represents which material is easier to recycle. Each one of the most used 12 material types that are assigned to their corresponding "Recycling as a Percentage of Generation," For example, Paper and Paperboard are 0.66, while the glass is 0.27.

$$Recycling\ Quality\ of\ Material\ Output\ indicator\ = \frac{0.66*(Mass\ of\ Paper\ and\ paperboard\ genrated + 0.27*(Mass\ of\ Glass\ Genetared) + 0.33*(Mass\ of\ Steel\ Generated) + ..etc}{Total\ Mass\ of\ Material\ Generated*0.6} \quad (15)$$

The Multiplication by 0.6 is to set the limit to 60%, which close to the highest recycled material percentage in the market.

$$Material\ Loss\ (Output)\ Index = \frac{Diversion\ Rate\ Percentage\ indicator + Hazardous\ Waste\ Recovered\ Indicator + Recycling\ Quality\ of\ Material\ Output\ Indicator}{3} \quad (16)$$

The Result for the "Material Loss (output) Index" will be one of the sixth values that will be used to calculate the final Circular Economy Metric.

g) Circular Economy Metric

After Calculating all the indexes of the six categories, the values can be used to calculate the Circular Economy Metric in two ways. Either the Linear Average or the Linear Average. While the Linear average is a simpler method, however, the Bilinear average gives a more accurate representation of the overall average. The bilinear average will be used later for the comparison between different sections.

The Six Categories: (Energy Input), (Durability), (Emission Levels), (Water Input and Output), (Material Input), and (Material losses (Output)) will be assigned with the C1 to C6 annotations. The averages equations are as follows:

$$CE\ Linear\ Average = \frac{C1+C2+C3+C4+C5+C6}{6} \quad (17)$$

C.E. Bi-Linear Average will use Equation (1). Each category will be multiplied by all the other categories over the total number of terms.

$$CE\ Bilinear\ Average = \frac{(C1*C2 + C1*C3 + C1*C4 + C1*C5 + C1*C6 + C2*C3 + C2*C4 + C2*C5 + C2*C6 + C3*C4 + C3*C5 + C3*C6 + C4*C5 + C4*C6 + C5*C6\ )}{15} \quad (18)$$

When the company does not have sufficient data for a particular indicator, The Calculator will give the company the option to assign "I do not have enough data for this category", the average equation will not calculate this value and thus will not affect the final C.E. metric value.

3.3. Plastic use during the Pandemic

Since the beginning of the Coronavirus (COVID-19) pandemic in 2020, the use of plastic has surged. Plastic surgical masks, gloves, protective equipment are being used in the effort in reducing sharing items between people to limit the spread of the coronavirus [26]. It might be unrealistic to demand the stop of using plastic during a public health crisis, however, the type of plastic being is as much important to the environment.

Many types of plastic being used are non-recyclable, the use of recyclable plastics is significant to the goals of C.E. This goal is covered in the calculator in the “Material Output” Characteristic, reporting the use of a material type that is recycled acquires higher Material Output Index and hence higher overall C.E. score.

3.4. Website testing company

The procedure for filling the C.E. calculator website, the sample company, is Google for its 2018 Sustainability Environmental Report [24].

Fig. 6 Shows the Homepage of the website where the company industry type is sellected.

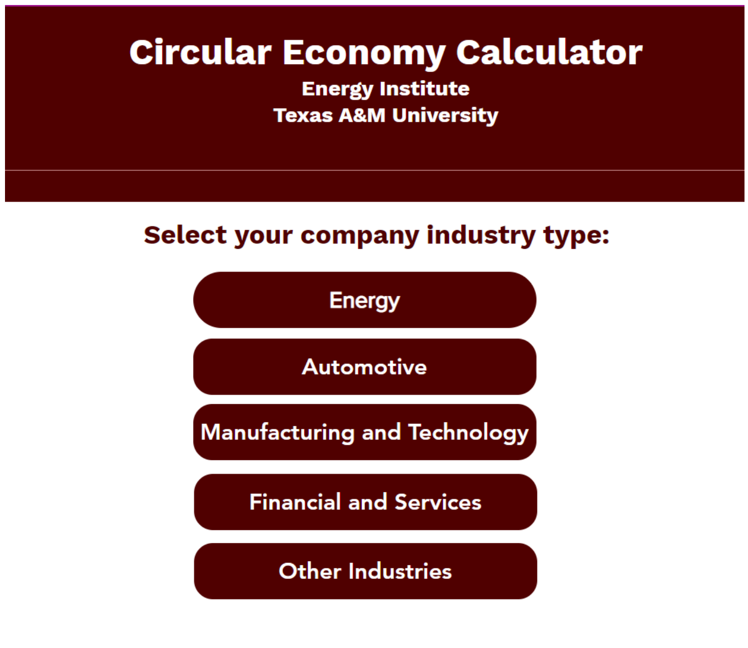


Figure 6: Selecting Company Type.

After Selecting the Company type, Fig. 7 shows the list of instructions for filling the calculator. The Inserted data can have any units as long as they are consistent through each section.

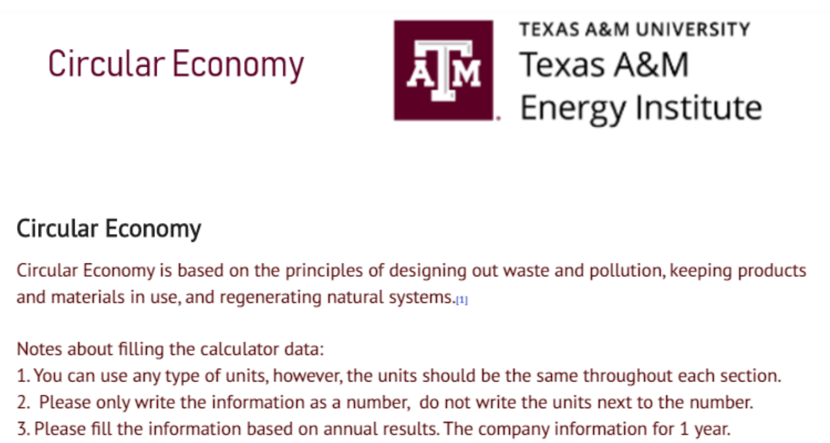


Figure 7: Website Calculator - C.E. Calculator Instructions List.

Fig. 8 Shows the Energy Category, 96, and 4 have the Unit of percentage (%). From calculating the energy from Electricity and Natural Gas. 100 and 0 represent the percentage of renewably produced from projects owned by Google.

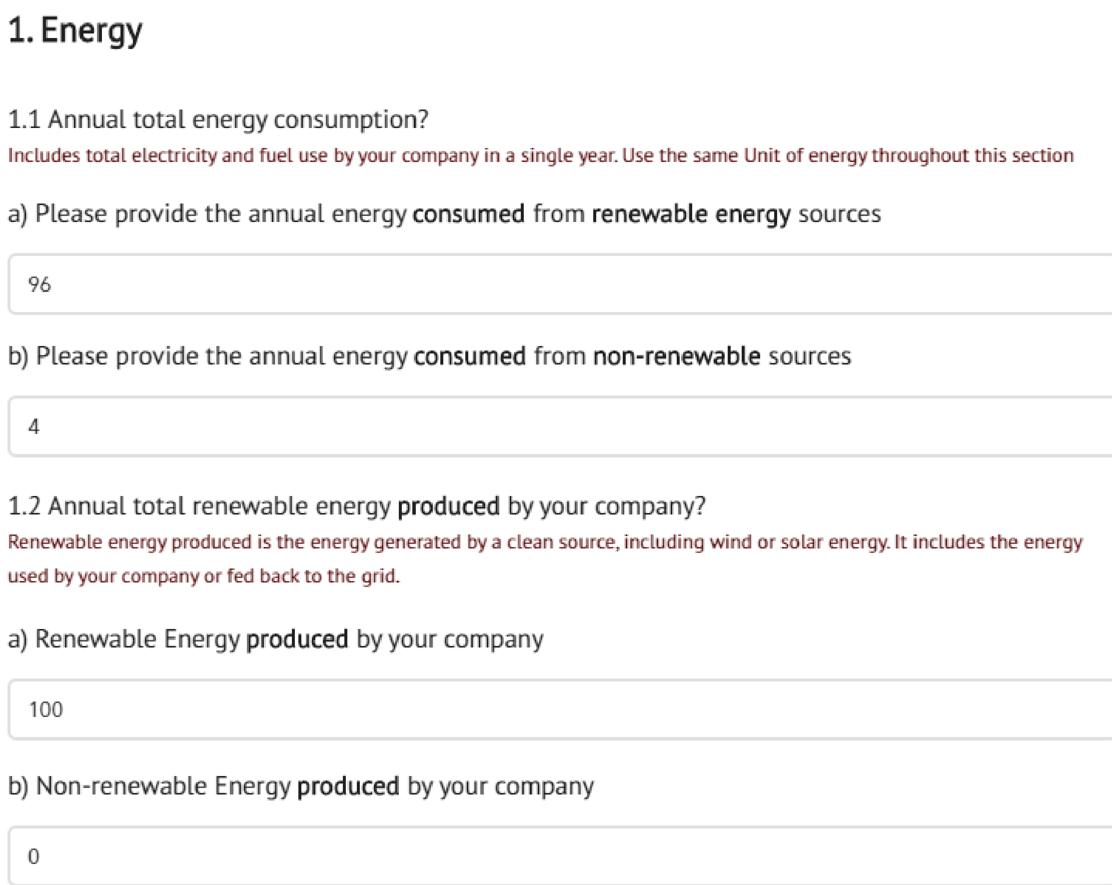


Figure 8: Website Calculator - Energy Category.

Google did not report any of the durability information in their sustainability reports. All the questions were set to "No" in Fig. 9.

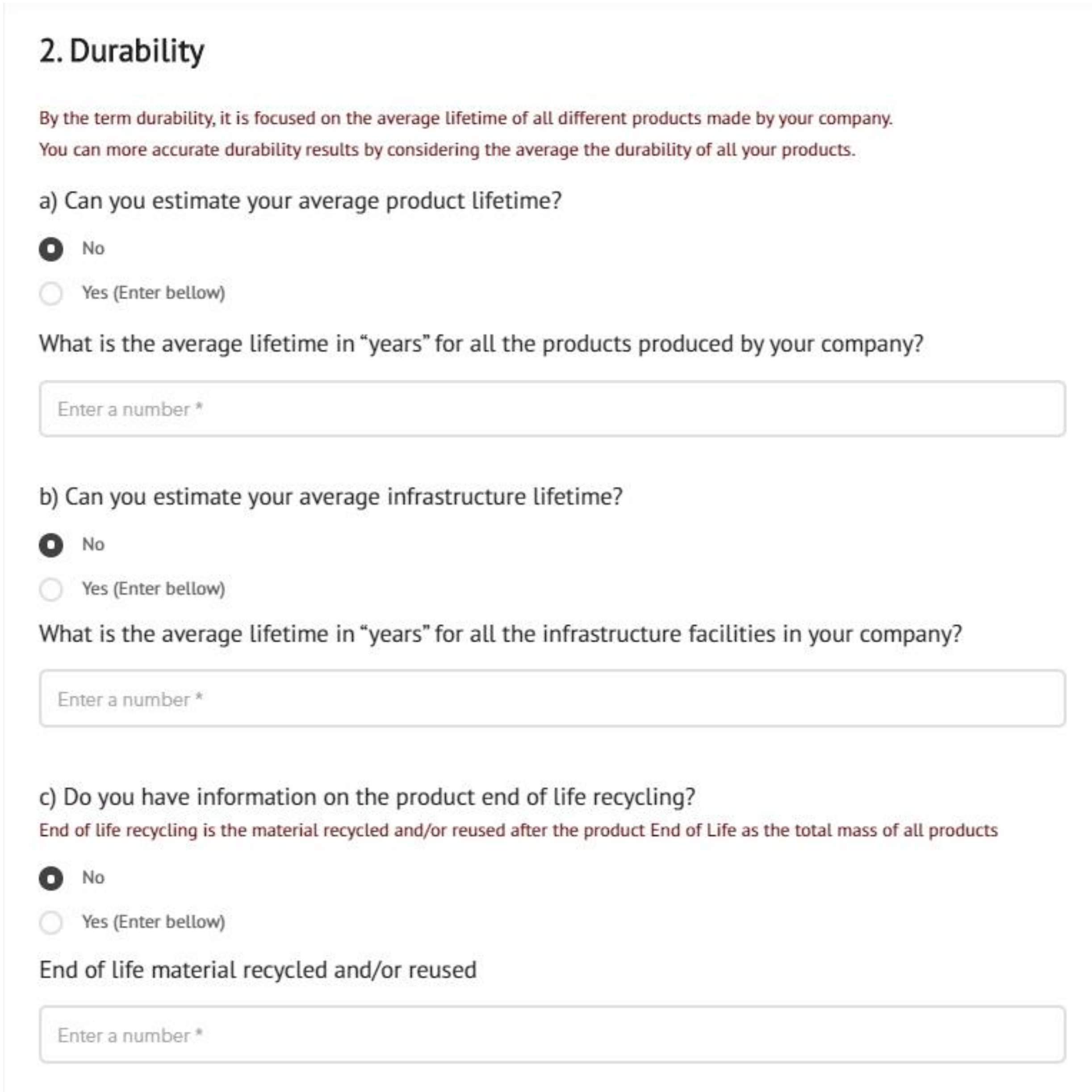
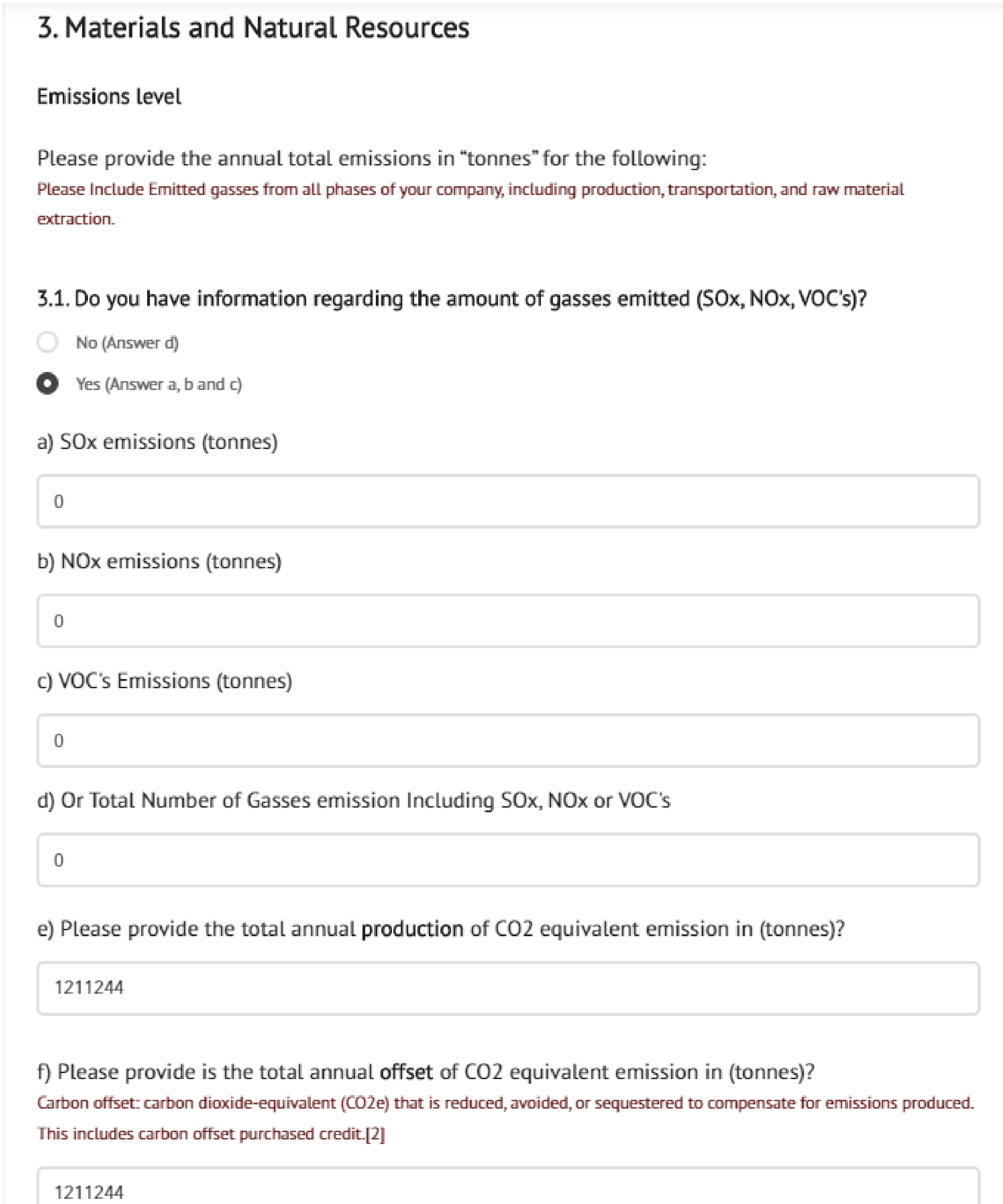


Figure 9: Website Calculator - Durability Category.

Section 3 of the Materials and Natural Resources is shown in Fig. 10, The CO_2 equivalent emissions were inserted in (tonnes) units in part e, and the CO_2 offset projects reported the same number, which resulted in zero CO_2 net emissions. No Other gasses were emitted so "zero" were inserted in parts (a) to (d).



3. Materials and Natural Resources

Emissions level

Please provide the annual total emissions in "tonnes" for the following:
Please Include Emitted gasses from all phases of your company, including production, transportation, and raw material extraction.

3.1. Do you have information regarding the amount of gasses emitted (SOx, NOx, VOC's)?

No (Answer d)

Yes (Answer a, b and c)

a) SOx emissions (tonnes)

0

b) NOx emissions (tonnes)

0

c) VOC's Emissions (tonnes)

0

d) Or Total Number of Gasses emission Including SOx, NOx or VOC's

0

e) Please provide the total annual **production** of CO2 equivalent emission in (tonnes)?

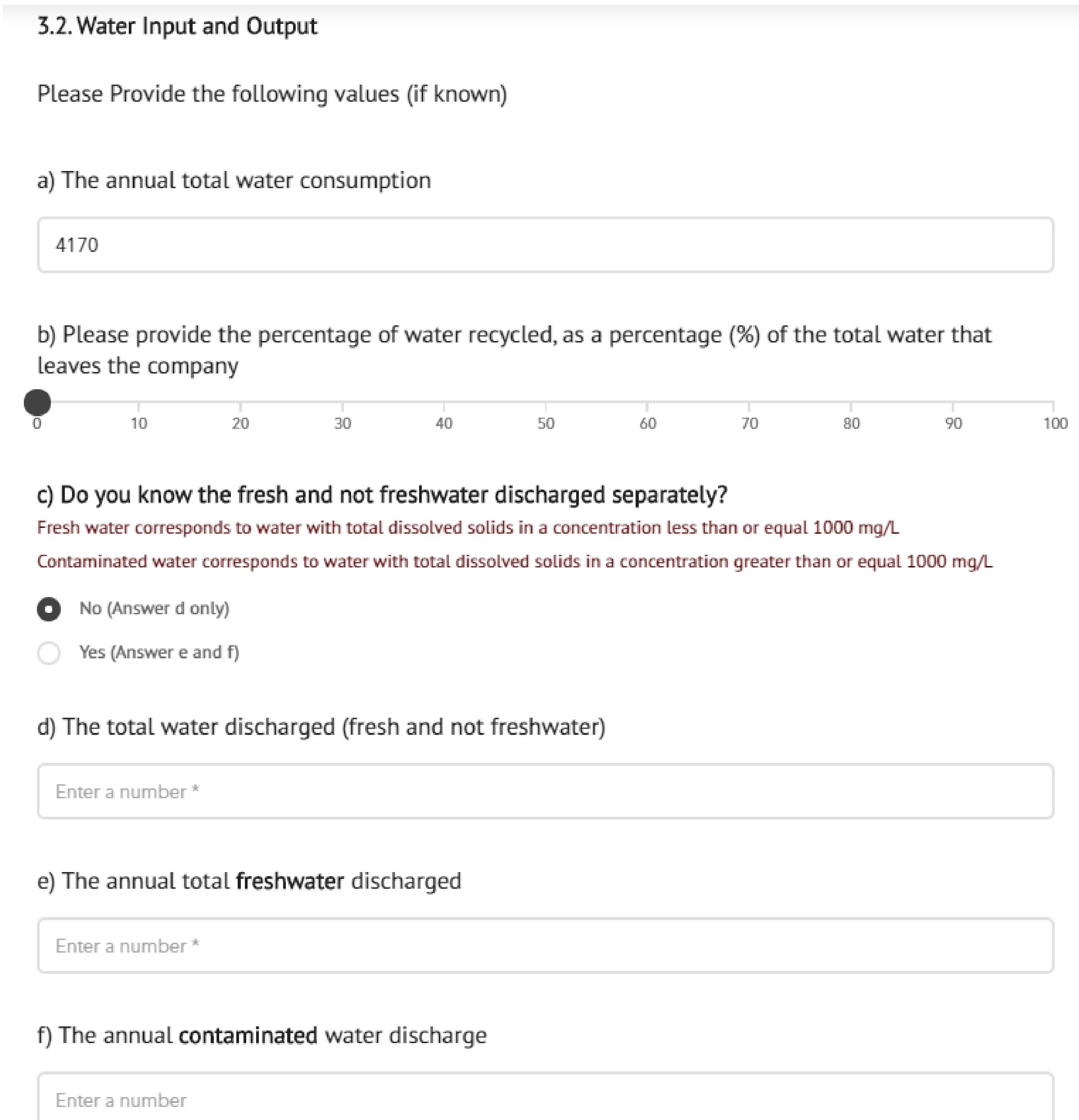
1211244

f) Please provide is the total annual **offset** of CO2 equivalent emission in (tonnes)?
Carbon offset: carbon dioxide-equivalent (CO2e) that is reduced, avoided, or sequestered to compensate for emissions produced. This includes carbon offset purchased credit.[2]

1211244

Figure 10: Website Calculator - Emissions Category.

The Water Input and Output Category is shown in Fig. 11, The annual water consumption (in million gallons) was the only number reported by Google reports in this category, which is not enough to create a full estimation of their water circularity process. The discharged water and type of discharged water should be considered. This category will not be included in the final C.E. Metric value as no sufficient data is provided.


3.2. Water Input and Output

Please Provide the following values (if known)

a) The annual total water consumption

4170

b) Please provide the percentage of water recycled, as a percentage (%) of the total water that leaves the company

0 10 20 30 40 50 60 70 80 90 100

c) Do you know the fresh and not freshwater discharged separately?

Fresh water corresponds to water with total dissolved solids in a concentration less than or equal 1000 mg/L

Contaminated water corresponds to water with total dissolved solids in a concentration greater than or equal 1000 mg/L

No (Answer d only)

Yes (Answer e and f)

d) The total water discharged (fresh and not freshwater)

Enter a number *

e) The annual total **freshwater** discharged

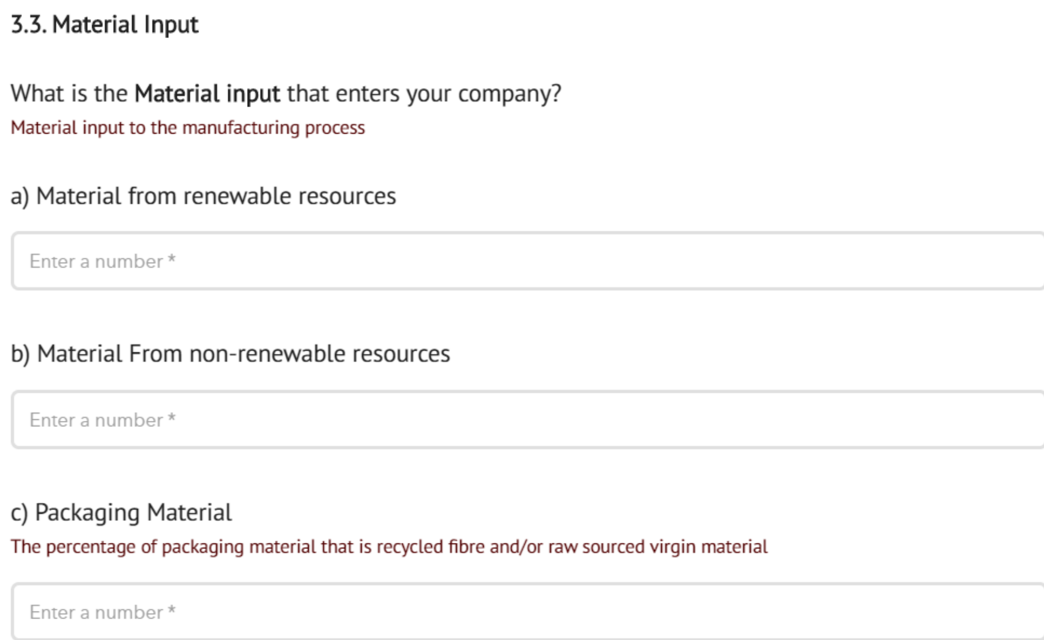
Enter a number *

f) The annual **contaminated** water discharge

Enter a number

Figure 11: Website Calculator – Water Input and Output Category.

The Material input category is shown in Figure 12. The report showed few Material input data such as (Components used for machine upgrades that were refurbished). However, no data was reported that covers the overall material used. This category does not have sufficient data to be included in the final C.E. Metric value.


3.3. Material Input

What is the **Material input** that enters your company?
Material input to the manufacturing process

a) Material from renewable resources

Enter a number *

b) Material From non-renewable resources

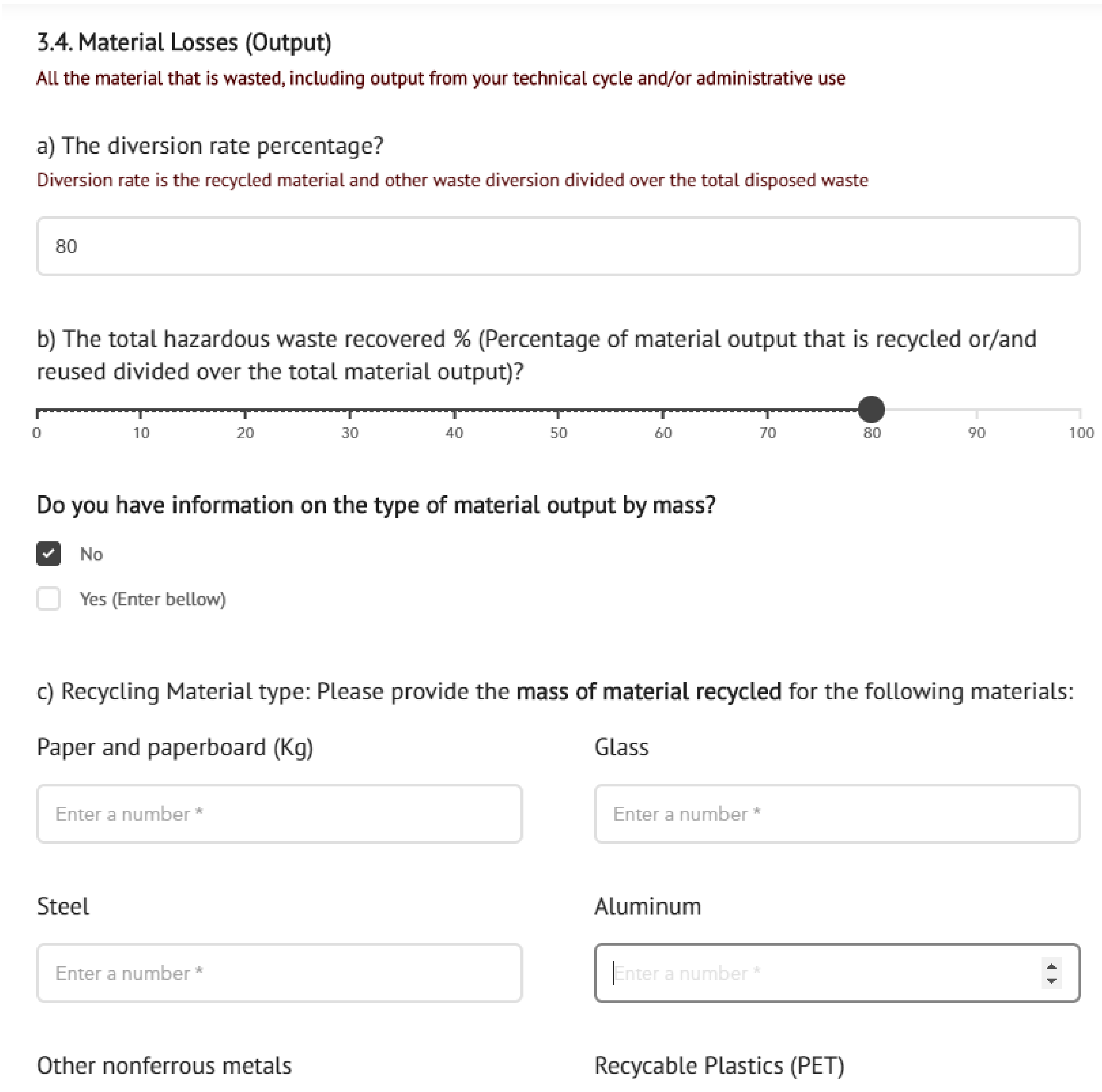
Enter a number *

c) Packaging Material
The percentage of packaging material that is recycled fibre and/or raw sourced virgin material

Enter a number *

Figure 12: Website Calculator – Material Input Category.

Fig. 13 Shows the Material losses (Output) Category, The diversion rate is 80%, while the hazardous material is not directly reported in the sustainability report, it is also assumed to be equal to the diversion rate, as the reported number did not specify the level of hazardousness of the diverted material. The material Output types were not reported, and hence and hence the "No" box was ticked.



3.4. Material Losses (Output)

All the material that is wasted, including output from your technical cycle and/or administrative use

a) The diversion rate percentage?

Diversion rate is the recycled material and other waste diversion divided over the total disposed waste

80

b) The total hazardous waste recovered % (Percentage of material output that is recycled or/and reused divided over the total material output)?

0 10 20 30 40 50 60 70 80 90 100

Do you have information on the type of material output by mass?

- [x] No
- [ ] Yes (Enter bellow)

c) Recycling Material type: Please provide the **mass of material recycled** for the following materials:

Paper and paperboard (Kg)

Enter a number *

Glass

Enter a number *

Steel

Enter a number *

Aluminum

Enter a number *

Other nonferrous metals

Recycable Plastics (PET)

Figure 13: Website Calculator – Material Output Category.

The C.E. Metric should only include the categories that have sufficient data. The Energy, Emission, and Material Output are the categories with enough/adequate data to be considered. This can be defined as presented in Fig. 14.

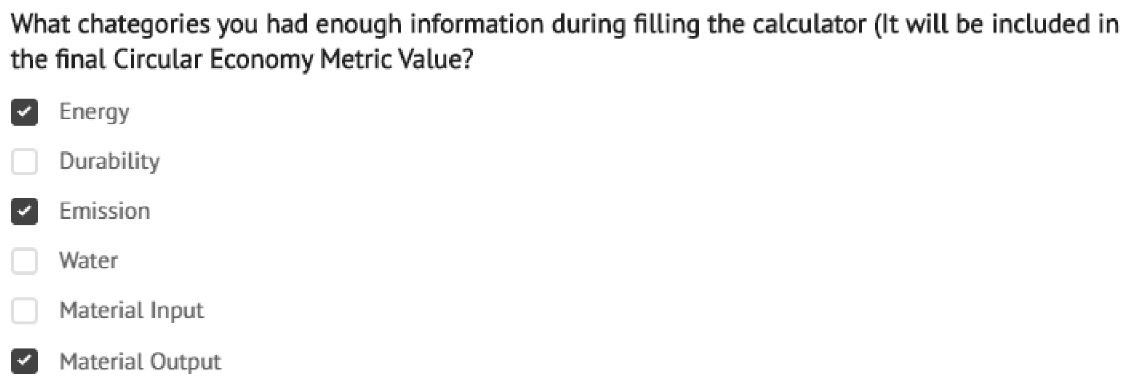


Figure 14: Choosing Characteristics for C.E. metric.

Fig. 15 shows the results for this test. Every index falls between the value of 0 and 1. The first two numbers represent the average C.E. metric in 2 different average methods, while the rest of the numbers represent the index for each of the six categories.

Figure 15: Google 2018 sustainability test results.

3.4. Testing the C.E. tool

3.4.1. Manufacturing and Technology - 2 companies.

Two technology companies were tested on the C.E. toolbox, Apple [25], and Google [24] for the years 2012, 2015, and 2018. The following results were obtained, as shown in Fig. 16. Both companies are showing an increase in their total C.E Metric. However, Google is showing a steeper increase, which means it is a more accelerated transition toward circularity.

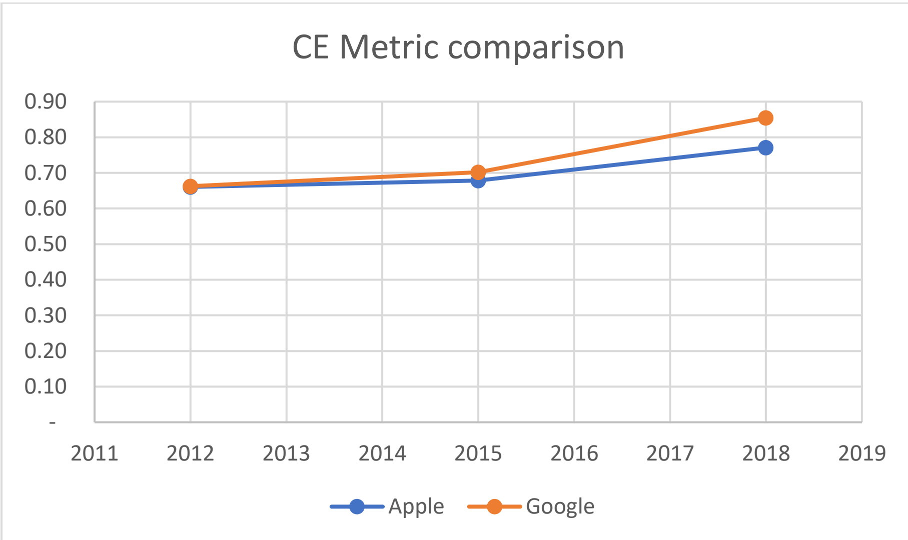


Figure 16: Total C.E. Metric for each company.

Fig. 17 shows the comparison between Apple and Google across the three different characteristics. Google is showing better C.E. indexes in all three characteristics.

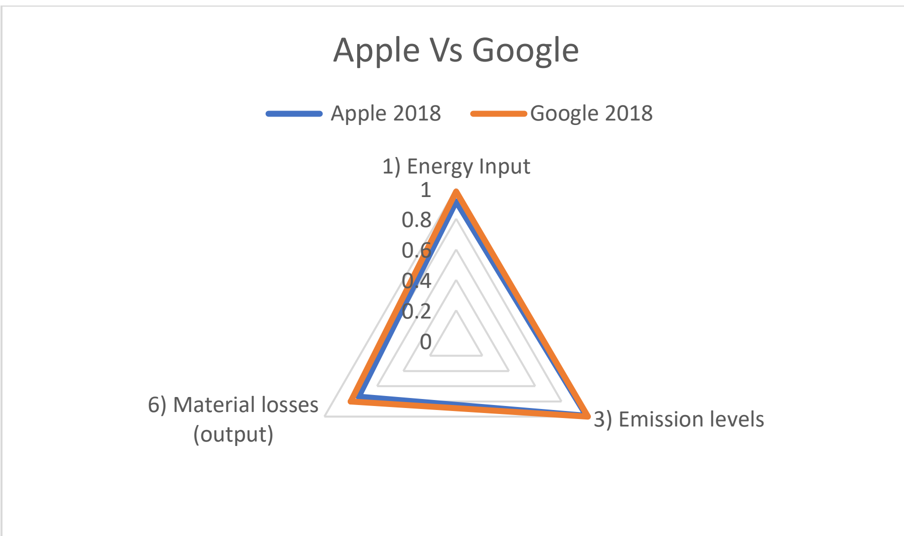


Figure 17: The comparison between Apple and Google in 2018.

Fig. 18 is showing a comparison between the characteristics over the years 2012, 2015, and 2018. The durability and emission levels are almost constant, however, the highest increase is the Energy Input and Material Losses characteristics.

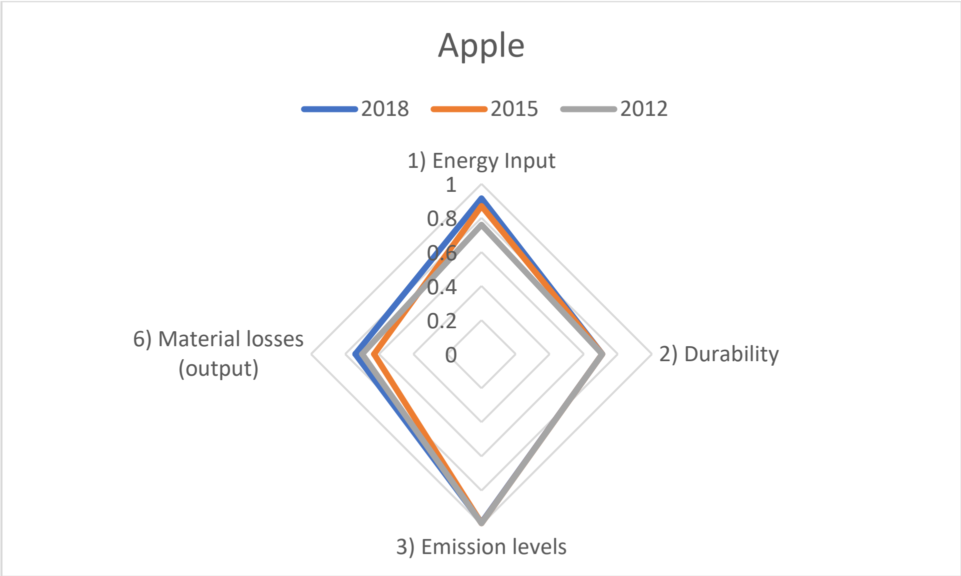


Figure 18: Apple Indicators comparison in 2012, 2015, and 2018.

Fig. 19 is showing a comparison between the characteristics over the years 2012, 2015, and 2018. The emission levels indicator is constant at 1, however, the highest increase is the Energy Input.

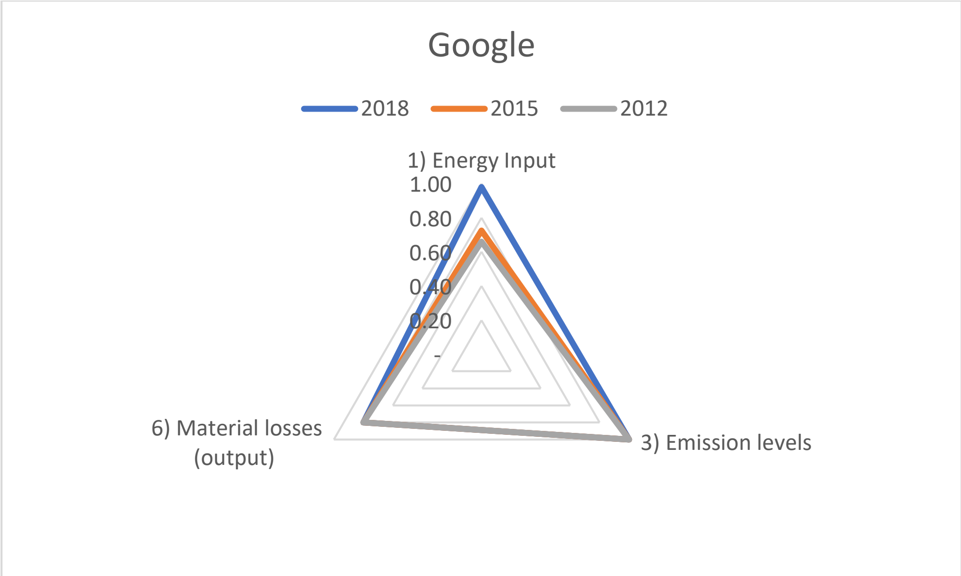


Figure 19: Google Indicators comparison in 2012, 2015, and 2018.

Explanation and recommendations:

Both apple and google are showing higher than average circularity metric results, and an improvement in their circularity over the years. However, Google is showing a higher slope as a result of its Energy input Characteristic. Google Renewable Energy consumed increased from 32% in 2012, to 96% in 2018. Although both Google and apple consume 100% renewable energy in 2018 for their electricity, however, Apple still uses a higher percentage of Natural Gas as an energy source, which resulted in lowering their Energy input indicator, and hence their C.E. Metric. The use of more Natural Gas was the main factor in setting the difference between the two companies' circularity.

Both companies use carbon offset projects, which resulted in zero CO_2 net emissions, therefore 1.0 normalization factor in the (Emission levels) characteristic.

Both companies did not report sufficient data for their (Material input) and (Water) characteristics. Both companies only reported the "water consumption indicator," Other indicators are needed to evaluate the water circularity such as the (total water recycled), and (water discharge).

More data is needed to be submitted to both companies for the durability of their products. This includes their product lifetime and End of life recycling percentage. Apple's durability product lifetime was taken from non-official reports. Although Google did report the (Components used for machine upgrades that were refurbished) and their (Number of Components resold into the secondary market), However more data are needed to be enough to evaluate their products' total durability indicators.

3.4.2. Financial and Services - 2 companies.

Two Financial Companies were tested on the C.E. toolbox, Bank of America (BOFA) [27], and Wells Fargo [28] for the years 2016, 2017, and 2018. The following results were obtained, as shown in Fig. 20. Both companies are showing an increase in their total C.E Metric. However, Bank of America maintained a higher and constant circular metric, which means it is a more accelerated transition toward circularity, while Wells Fargo showed a huge increase between 2016 to 2017.

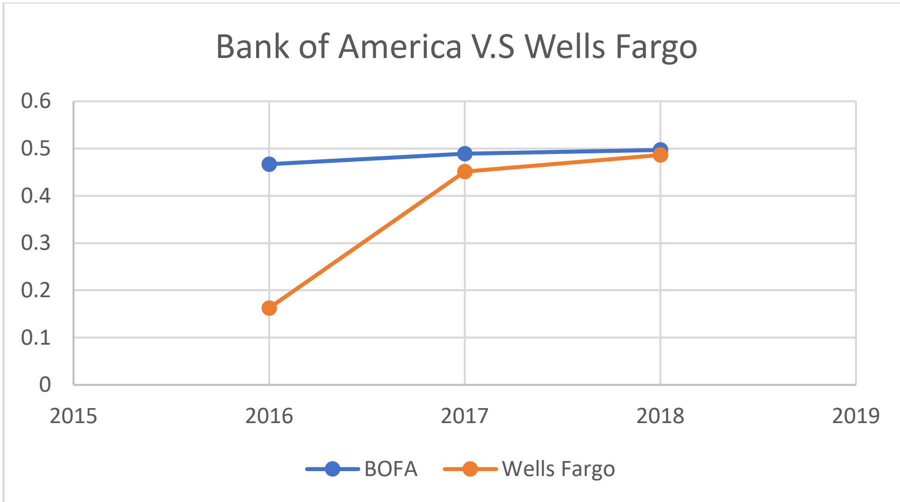


Figure 20: Total C.E. Metric for each company.

Fig. 21 shows the comparison that the Material Output characteristic is higher in Bank of America, while the Energy Input index is higher for Well Fargo. The Durability and Emission levels are almost the same.

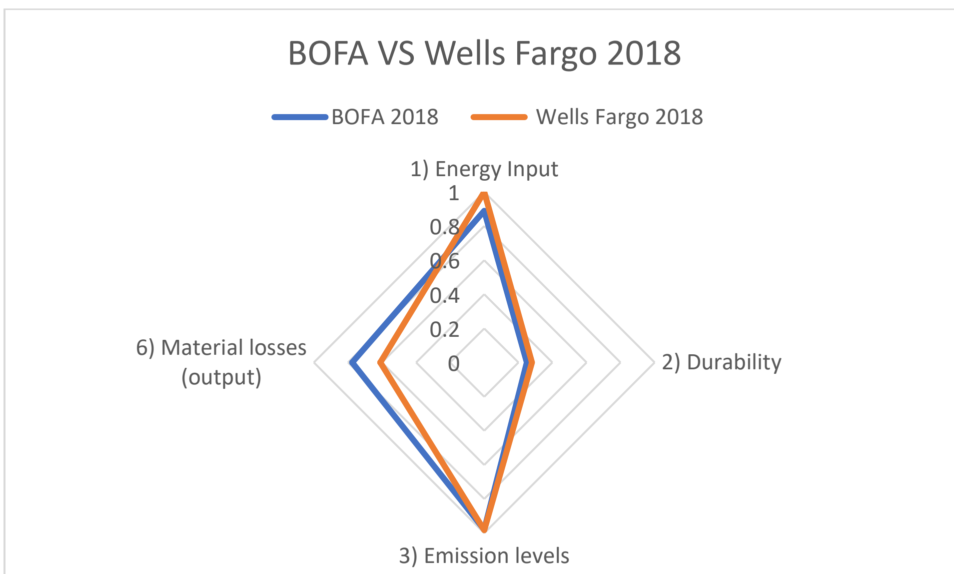


Figure 21: The comparison between Bank of America and Wells Fargo C.E. in 2018.

Fig. 22 is showing a comparison between the characteristics over the years 2016, 2017, and 2017. All the characteristics are almost constant, which relatively high index, except for the durability.

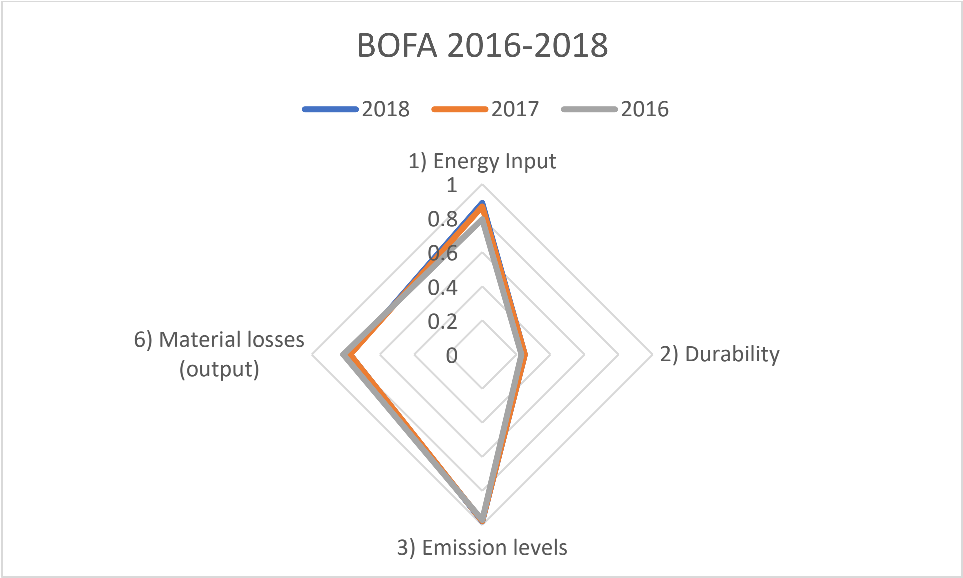


Figure 22: Bank of America Characteristics comparison in 2012, 2015, and 2018.

Fig. 23 is showing a comparison between the characteristics over the years 2012, 2015, and 2018. Three of the characteristics are showing a slight increase during the years, except for the Energy input which showed a dramatic increase in 2016.

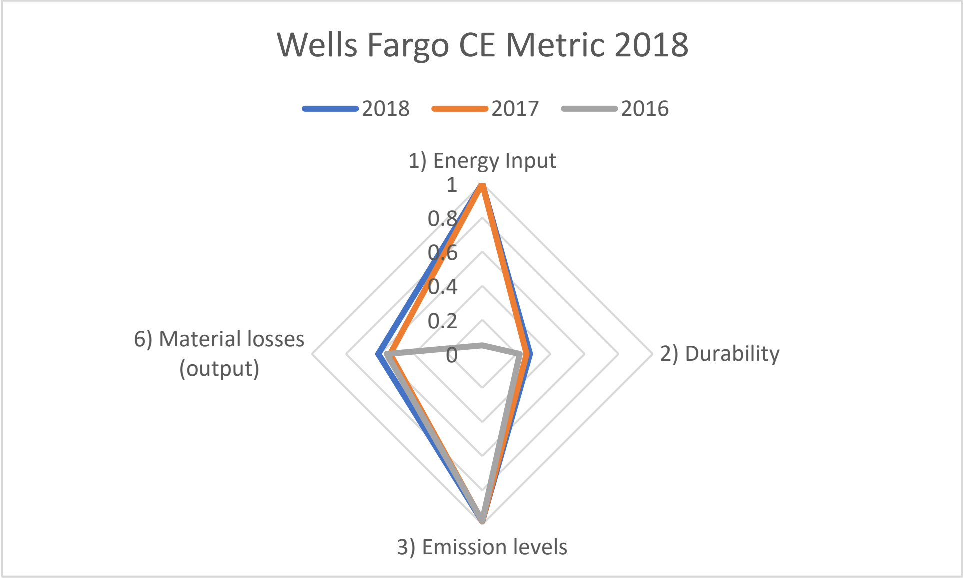


Figure 23: Wells Fargo Indicators comparison in 2012, 2015, and 2018.

Explanation and recommendations:

Both companies are showing an increase in their C.E. Metric results, although its much steeper in Wells Fargo back. The most significant factor in the increase in 2016 to 2017 is the installation of Renewable Energy projects, which increased the Produced/Purchased Renewable energy from 5% in 2016 to 100% in 2017. A very low Energy Input characteristic value caused the entire C.E. metric value to be much lower, this is because the average is calculated using a Bi-linear Average (Eq 1 and 18).

Bank of America data is almost constant for most of the indicators, except for the recycling which is showing a slight improvement. And also it showing an improvement in the Renewable energy production projects.

Both companies reported the percentage of their buildings that have a LEED certificate, it was constant around 23%-28% for both companies. This number was the only indicator used in the Durability characteristic.

Both banks did report sufficient data for the four calculated characteristics, however not sufficient data was reported for the "Material Output" and few data for the "Water" characteristics that were not enough to evaluate the circularity of their water recycling. It is recommended to focus on these two characteristics for a complete improvement for all the C.E. goals.

3.4.3. C.E. Metric Comparison

Evaluating the C.E. for Fortune 500 companies and ranking them based on their circularity would get more attention from the companies, media and researchers [30]. Table 5 shows the companies that were tested, their C.E. Bi-linear average, the categories used to calculate their C.E. Metric, and the company type.

Table 5: C.E. Metric comparison for a few Fortune 500 companies.

All Companies	**C.E. Metric**	**Categories involved**	**Company Type**
Google	0.855	1,3 and 6	Manufacturing and Technology
Apple	0.698	1,2,3, and 6	Manufacturing and Technology
Bank of America	0.497	1,2,3 and 6	Financial and Services
Wells Fargo	0.486	1,2,3, and 6	Financial and Services
Shell [31]	0.201	1,3,4, and 6	Energy
ExxonMobil [32]	0.117	1,3,4, and 6	Energy

The categories numbers as follows, 1 Energy Input, 2 Durability, 3 Emission levels, 4 Water Input and output, 5 Material input, and 6 Material losses (output).

To get more accurate results, the same categories should be used in all the companies, however, not sufficient data is publicly reported by companies to make the full comparison. The C.E. Metric comparison is shown in Fig. 24.

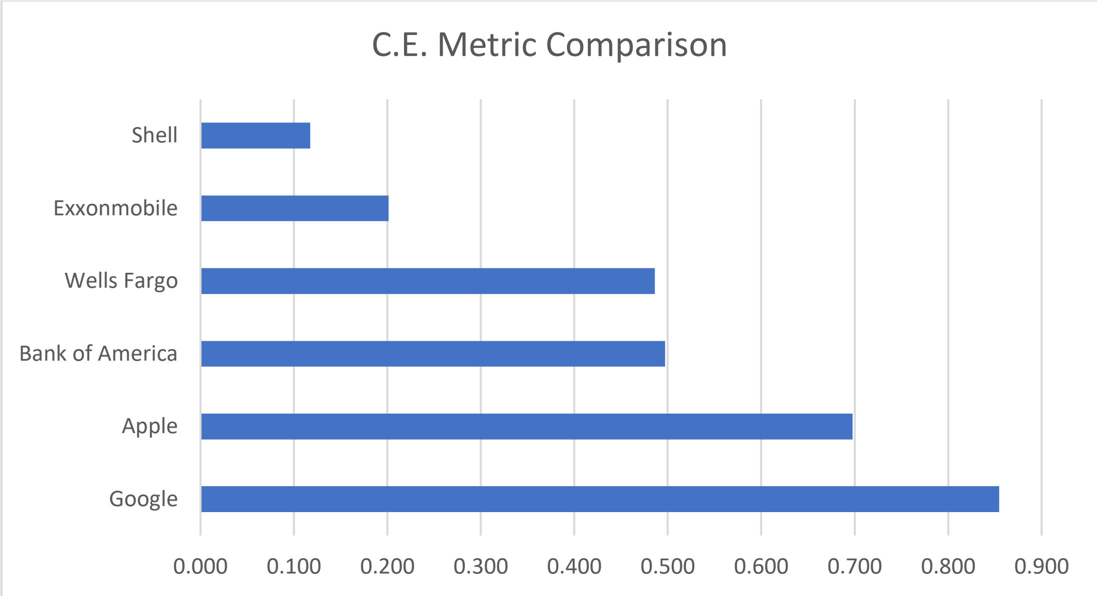


Figure 24: C.E. Metric Comparison

The two energy companies Shell and ExxonMobil showed the lowest C.E. Metric results because of their high CO_2-Equivalent and Acidic Gasses emissions. As well as their low renewable energy production projects in comparison to the high Fossil fuel production. Note that the comparison between 6 companies is a small sample to conclude that the company type is correlated to the C.E. Metric value more testing should be done for different companies for the more informed analysis.

3.5. Financial Analysis

Companies have different goals regarding sustainability, safety, or circular economy. Some companies use the analysis used in Eq. 19 to estimate whether a project meets their sustainability or safety goal [33][34]. This analysis can be applied for future work for the circular economy. Consider the term "Annual sustainability and Safety Profit" ASSPp

$$ASSPp = AEPp\left(1 + \sum_{i=1}^{N\ Indicators} Wi\ \left(\frac{Indicators\ Base,i - Indicator\ p,i}{Indicator\ Base,i - Indicator\ Target\ i}\right)\right) \quad (19)$$

Where, AEPp = Annual Economic Profit. N Indicators are Index for sustainability or safety indicators, Wi= Weighting factor: Ratio between the importance of i^{th} indicator and its annual net economic profit. This Wi factor is relative to the company's goals. The denominator (Indicator Base,i-Indicator Target i) represents the maximum desired improvement for each indicator. The numerator (Indicators Base,i-Indicator p,i) is the improvement when the difference is positive or deterioration when the difference is negative, where p^{th} is the design option. Therefore, the ratio represents the design option contribution toward the company's sustainability or safety goal.

This term is applied to find the term (Sustainability and Safety Weighted Return of Investment Metric) SASWROIMp

$$SASWROIMp = \frac{ASSPp}{TCIp} \quad (20)$$

Where TCI is the Total Capital Investment. If the SASWROIMp value meets the company (Return of Investment) ROI threshold, then the company would consider the project. This same concept can be used to be applied to the six C.E. goals in this project, this project can be substituted in the N indicator term, and the company can consider a new threshold ROI goal for C.E.

4. FUTURE WORK SUGGESTIONS

The focus on this project testing was done on large companies as they report more data. It is recommended that testing should be done on a larger scale on companies on all size scales. A higher number of companies testing will show more accurate results on the reported indicators, improved and working on which characteristics. These testing should be done on all four sectors; this will allow more analysis opportunities on the results. Testing could also be done for companies in different countries, as European countries are known to be leading in the transition towards C.E., their results could be compared to that is of the U.S. Or even more countries from different regions. Many questions could be asked, is there anything common between companies that have transition further to C.E. Are private or public companies more likely to be more circular?

Also, more testing will create the distribution for the different indicators that have maximum and minimum limits, such as emissions and durability, and hence recreate the boundaries to create a more fair comparison for the C.E. metric results.

A collaboration with companies could be done for a financial analysis of the C.E. projects [35]. A study of the correlation between the cost of the projects that the companies constructed to improve their circularity in relation to the increase in their C.E. metric. This could be used to understand the project types that would have the most significant effect of C.E.

5. CONCLUSION

Circular Economy definition includes a cycle of natural resources through its entire life cycle. The Companies sustainability report is sufficient data in some areas such as Emissions, energy input, and Material Output while it lacks reporting or/and measuring in other categories such as material input, durability, and water in and out.

Most companies testing is showing improvements in the emissions category; less CO_2 is being emitted, as well as constructing CO_2 offset projects. While most companies report their diversion rates or recycling rates, however, more companies should start considering and reporting material that is more recyclable. Also, the material input source, whether it is renewable or not, should be considered and reported. Water consumption is reported in most companies, but it is not sufficient to evaluate the entire cycle of water for the company, indicators such as withdrawal amount and disposal purity should also be taken into consideration for better water circularity assessment. Some of the big companies are showing a huge transition toward green energy consumption, which is a significant factor toward circularity. The durability is often being neglected in sustainability reports as it is a new C.E. concept, the products and infrastructure lifetimes should be reported, and efforts should be made to change the way products are designed to last a long time.

Some companies might report their data in reference to a year they set and compare next years to that year, while this method is useful for the company self-assessment of their circularity improvement, the baseline for comparison should be more unified between all companies for more clear comparison for the investors and the community.

Some companies appear to not report the numbers that might show a negative impact on their sustainability report. This will not create a fair, holistic assessment of the circularity of the companies. While most companies tested showed an improvement in circularity, it might be due to not reporting the numbers that are getting worse. It is highly recommended that a holistic unified Circular Economy indicators should be unified between all the companies to assess circularity, where all companies should report indicators that covers all aspect of C.E., the indicators used in this research could be used as a reference for this reporting. Measuring C.E. transition accurately will allow policy makers to have a more informed decision on what areas their companies need to focus on in terms of circularity.

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APPENDIX

1. Sustainability Reports Data

1.1 Data from Apple sustainability reports for 2012, 2015 and 2018. The data was used in 1.2.2.1. Manufacturing and Technology - 2 companies to evaluate the companies circuity.

Current Indicators	Apple indicator name	Apple 2018	Apple 2015	Apple 2012
1. Energy				
1) Non-Renewable Energy **consumed** (MWh) [15]	renewable calculated bellow	0.17	0.26	0.48
2) Renewable Energy **consumed** (MWh) [15]		0.83	0.74	0.52
3) Non-renewable Energy **produced** MWh		0	0	0
4) Renewable energy **produced** (MWh)	they produce renewable but (	1	1	1
Durability				
Average Products lifetime?	softeware updates 5 yrs, aver	4.25	4.25	4.25
Infrastructure lifetime (years)		30	30	30
End of life recycling percentage	N/A			
Emission				
1) CO2 emission (ton) (equivalent) [15] (7 types of gasse	Greenhouse Gas Emissions (M	583,820	383,470	362,440
2) SOx, Nox or VOC's (tonnes)	N/A	0	0	0
3) CO2 offset	N/A	0	0	0
Water				
1) Water Consumption (m^3) [15]	million gallons	1,260	573	345
2) Pecentage of water recycled [26]	N/A			
3) Water discharge (fresh water)				
4) Water discharge (other water) (m^3) [15]				
Material input				
1) Non-renewable material (kg) [15] %?	N/a			
2) Renewable material used (kg) [15]				
3) Packaging (Recyled fiber + raw sourced virgin fiber % of the total packaging) [25]		100%	60%	N/a
Mateial output				
1) Diversion rate (%) (Recycled and other diversions / to	pounds	74	63	70
2) Hazardous waste recovered %	hazardous waste amount only			
3) Mass of material recycled by type (kg) [16]	pounds recycled	108,515,200	19,599,570	11,464,020

1.2. Data from Apple sustainability reports for 2012, 2015 and 2018. The data was used in 1.2.2.1. Manufacturing and Technology - 2 companies to evaluate the companies circuity.

Current Indicators	Google indicator name	Google 2018	Google 2015	Google 2012
1. Energy				
1) Non-Renewable Energy **consumed** (MWh) [15]		4	55.00	68.00
2) Renewable Energy **consumed** (MWh) [15]	100% ren	96	45.00	32.00
3) Non-renewable Energy **produced** MWh		0.00	0.00	0.00
4) Renewable energy **produced** (MWh)	Produced renewable energy,	1	1.00	1.00
Durability				
Average Products lifetime?	N/A	N/A		
Infrastructure lifetime (years)	N/A	30.00	30.00	30.00
Product afterlife		0%		
Emission				
1) CO2 emission (ton) (equivalent) [15] (7 types of gasse	Operational emissions were	1,211,224.00	1,749,207	1,519,787
2) SOx, Nox or VOC's (tonnes)		0	0	0
3) Co2 offset	tonnes over 12 years since 2	1,211,224.00	1,749,207	1,519,787
Water				
1) Water Consumption (m^3) [15]	million gallons	4,170		
2) Pecentage of water recycled [26]				
3) Water discharge (fresh water)				
4) Water discharge (other water) (m^3) [15]				
Material input				
1) Non-renewable material (kg) [15] %?		81.00	48.00	
2) Renewable material used (kg) [15]	Components used for machin	19.00	52.00	
3) Packaging (Recyled fiber + raw sourced virgin fiber %	N/A			
Mateial output				
1) Diversion rate (%) (Recycled and other diversions / to	year 2015 was not reported,	80.00	80.00	80.00
2) Hazardous waste recovered %	No hazardous waste			
3) Mass of material recycled by type (kg) [16]				

1.2 Data from Bank of America sustainability reports for 2016, 2017 and 2018. Used in the Financial and Services tool testing.

Current Indicators	Apple indicator name	BOFA 2018	BOFA 2017	BOFA 2016
1. Energy				
1) Non-Renewable Energy **consumed** (MWh) [15]	Mwh (Total energy consumpt	511,274.17	606,914.17	952,663.17
2) Renewable Energy **consumed** (MWh) [15]	MWh	1,798,110	1,702,470	1,356,721
3) Non-renewable Energy **produced** MWh	%	0	0	0
4) Renewable energy **produced** (MWh)	PV cell projetcs (%)	100	100	100
Durability				
1) LEED certifications of buildings (% of total area of all	Percentage %	25	25	23
2) Infrastructure lifetime (years)		N/A	N/A	N/A
Emission				
1) CO_2 emission (ton) (equivalent) [15] (7 types of gasse	Metric tones, location-based	1,070,070	1,183,121	1,515,335
2) SOx, Nox or VOC's (tonnes)	Metric tonnes	55	54	55
3) CO_2 offset		0	0	0
Water				
1) Water Consumption (m^3) [15]	Only water withdrawal is reported			
2) Pecentage of water recycled [26]				
3) Water discharge (fresh water)				
4) Water discharge (other water) (m^3) [15]				
Material input				
1) Non-renewable material (kg) [15] %?	N/A			
2) Renewable material used (kg) [15]	N/A			
Mateial output				
1) Diversion rate (%) (Recycled and other diversions / total waste)		55	55	63
2) Hazardous waste recovered %		100	100	100
3) Mass of material recycled by type (kg) [16]	N/A			

1.3. Data from Wells Fargo sustainability reports for 2016, 2017 and 2018. Used in the Financial and Services tool testing.

Current Indicators	Wells Fargo indicator nai	Wells Fargo 2018	Wells fargo 2017	wells fargo
1. Energy				
1) Non-Renewable Energy **consumed** (MWh) [15]	Produced/ purchased in the same category in wells fargo enviromntal report in %	0	0	95
2) Renewable Energy **consumed** (MWh) [15]		100	100	5
3) Non-renewable Energy **produced** MWh		0	0	95
4) Renewable energy **produced** (MWh)		100	100	5
Durability				
1) LEED certifications of buildings (% of total area of all branches)		28	26	22
Infrastructure lifetime (years)	N/A			
Emission				
1) CO2 emission (ton) (equivalent) [15] (7 types of gasse	Total - Scope 3 (MTCO2e)	912,662	934,350	1,076,468
2) SOx, Nox or VOC's (tonnes)		0	0	0
3) CO2 offset				
Water				
1) Water Consumption (m^3) [15]	No enough information	8,154,835	8,243,146	9,096,117
2) Pecentage of water recycled [26]				
3) Water discharge (fresh water)				
4) Water discharge (other water) (m^3) [15]				
Material input				
1) Non-renewable material (kg) [15] %?	N/A			
2) Renewable material used (kg) [15]				
Mateial output				
1) Diversion rate (%) (Recycled and other diversions / to	Total recycling / total wate to	0.61	0.54	0.56
2) Hazardous waste recovered %	N/A			
3) Mass of material recycled by type (kg) [16]	N/A			

1.4. Data from Shell sustainability reports for 2018. Used in the Energy tool testing.

Current Indicators	Shell indicator name	Shell 2018
1. Energy		
1) Non-Renewable Energy **consumed** (MWh) [15]		1.00
2) Renewable Energy **consumed** (MWh) [15]		-
3) Non-renewable Energy **produced** MWh	10,000 megawatts (MW) in	10,000
4) Renewable energy **produced** (MWh)	44% share of 1,400 megaw	616
Durability		
Average Products lifetime?	N/A	
Infrastructure lifetime (years)	N/A	
End of life recycling percentage		
Emission		
1) CO2 emission (ton) (equivalent) [15] (7 typ	tonnes	71,000,000
2) SOx, Nox or VOC's (tonnes) (Acid gases an	tonnes	239000
3) CO2 offset		0
4) Flaring internsity	tonnes hydrocarbon flared	1500000
Water		
1) Water Consumption (m^3) [15]	million cubic metres GHGs	**147**
2) Pecentage of water recycled [26]		
3) Water discharge (fresh water)	calculated from withdrawn	52
4) Water discharge (other water) (m^3) [15]		
withdrawn=199		
Material input		
1) Non-renewable material (kg) [15] %?		N/A
2) Renewable material used (kg) [15]		
3) Packaging (Recyled fiber + raw sourced virgin fiber % of the total packaging) [25]		
Mateial output		
1) Diversion rate (%) (Recycled and other div	400 thousand tonnes reuse	0.20
2) Hazardous waste recovered %		
3) Hydrocarbon discharges to water (tonnes)	spills and discharge (volume addedd different steps) tonnes Sabotage spills +	3800
4) Mass of material recycled by type (kg) [16]		

1.5. Data from ExxonMobile sustainability reports for 2018. Used in the Energy tool testing.

Current Indicators	Exxon indicator name	Exxon 2018
1. Energy		
1) Non-Renewable Energy **consumed** [15]	billion gigajoules	1.50
2) Renewable Energy **consumed** [15]		
3) Non-renewable Energy **produced**	1934.5 million barrels	100
4) Renewable energy **produced**	500 megawatts, assumed 0	0
Durability		
Average Products lifetime?		N/A
Infrastructure lifetime (years)		N/A
End of life recycling percentage		
Emission		
1) GHG - CO2 emission (ton) (equivalent) [15]	tonnes	124,000,000
2) SOx, Nox or VOC's (tonnes)		370,000
3) CO2 offset		
4) Flaring internsity (% of total production)	million metric tons	4,000,000
Water		
1) Water Consumption (m^3) [15]	m^3	290,000,000
2) Pecentage of water recycled [26]		
3-4) Total discharge	(Withdrawal- consumption)	150,000,000
3) Water discharge (fresh water)		
4) Water discharge (other water) (m^3) [15]		
withdrawal m^3	440,000,000	
Material input		
1) Non-renewable material [15] %?		N/A
2) Renewable material used [15]		N/A
Mateial output		
1) Diversion rate (%) (Recycled and other diversions / total waste)		
2) Hazardous waste recovered %		
3) Hydrocarbon discharges to water	Tonnes, taken from 8600 ba	1173
4) Mass of material recycled by type (kg) [16]		