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Development of a Simplified Circularity Index for Sustainable Manufacturing

Ladislaus Aroguiaraj Joseph[1], Yih Tng Chong[2], Paul Nicholas Sharratt[3], and D Mohan Kumar[4]

1 HP Inc Singapore
2 Engineering, Singapore Institute of Technology, Singapore
3. Cluster Director, Chemical Engineering and Food Technology, Singapore Institute of Technology, Singapore
4. HP Inc, Singapore

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Current manufacturing processes are primarily based on the exploitation of virgin raw materials. This linear approach of utilizing raw materials and natural resources is under increasing pressure because of its environmental and economic disadvantages**.** The concept of circular economy is based on the reuse, recycle, recovery, and refurbishment of materials and products. With the current environmental degradation scenarios, we need to accelerate the transition towards a circular economy and ensure that we keep products, materials, and resources in the economy for as long as possible. The impact on the environment needs to be evaluated over the material life cycle, i.e., from raw material extraction to production, use, disposal, and recycling. With a well-coordinated effort, a circular economy can contribute to minimizing the generation of waste and lead to a transformation of the economy by creating a new and more sustainable manufacturing and remanufacturing processes. Currently, there are several indexes and indicators that allow companies to identify additional circular value from their products and materials and to analyze and evaluate a range of environmental, regulatory, and supply chain risks for their products and processes. Since current indexes and indicators may be complex for some manufacturing companies to adopt, this paper provides a simplified startup solution on the quantification of circularity that can lead to manufacturing firms taking interest and expanding to more complex mechanisms later. A Simplified Circularity Index for Products (SCIP) is proposed along with a case study. This index can be applied to support managers in these firms in assessing their level of circularity.

1. Introduction

The critical impact of the linear economy is on our ecosystems, leading to the urgent need for environmentally conscious design and manufacturing. Excessive pressure on our ecosystem also jeopardizes the provision of essential elements, such as water, air, and soil [1]

The linear model of "take-make-use-dispose" affects our ecosystem in different ways. The collection of raw materials leads to high energy and water consumption, emissions of toxic substances, and disruption of natural capital such as forests and lakes. Similarly, the products manufactured and their consistent raw material find their way to landfills, often leading to the leaching of toxic substances [2]. A good example is that more than 300 million tonnes of new plastic are produced worldwide yearly. Much of the plastic is dumped initially on land but washes into the sea via rivers and canals, and an estimated 5 million tonnes end up in the oceans. Some tiny granules of plastic known as microbeads, which are constituents of personal care products, can end up being consumed by fish, thus infiltrating the food chain that may affect human health.

In this way, the production of plastic in the "take-make-use- dispose" step-by-step scheme harms the supply of fish as an ecosystem service for the oceans and seas [3]

In addition to the damage caused by the linear economy to the ecosystem, the economic model also jeopardizes the supply of materials. This is caused by fluctuating raw material prices, scarce materials, geopolitical dependence on different materials, and increasing demand[4]

On the macro level, resource extraction and use account for 70% of all GHG emissions, which pushes global temperatures upwards. Our current linear economy is firmly steering us toward a 3 to 6-degree centigrade temperature increase. If we continue business-as-usual, we will emit 65 billion tonnes of Green House Gas GHGs) emissions in 2030. [5]. Global warming shows no signs of slowing, and the reality is that certain vulnerable cities and countries will face catastrophes that threaten much of the population

2. The Circular Economy

The impact to the ecosystem and global warming can be significantly addressed through the circular economy. The Circular economy is a tool to address greenhouse gas emissions; it allows us to satisfy global needs and wants, such as transport and nutrition, with less virgin material. Reduced demand for virgin materials means less extraction and processing and, consequently fewer emissions, offering a 39% reduction in greenhouse gas emissions if the circular economy is implemented globally [6].

Currently, economic growth is closely tied to material extraction, the use of resources such as water and land use, and overall environmental degradation. In many cases, in the linear economy, ‘growth’ itself relies on resource mismanagement and over-extraction, leading to broken economic systems [7].

By applying circular economy approaches, businesses potentially become more resilient and profitable by reducing their exposure to costly supply chain disruptions and resource price volatility. In fact, these businesses may attract investors keen to reach net-zero and achieve superior risk-adjusted returns [7].

Fig 1 shows the United Nations circularity framework. It illustrates a visual contrast between a linear and a circular economy model. It provides options to enable circularity integrated at the product level. We will use this as the basis of our study, where ‘circular components’ is defined as parts or modules that can be remanufactured, repurposed, recycled, reused, refurbished or repaired.

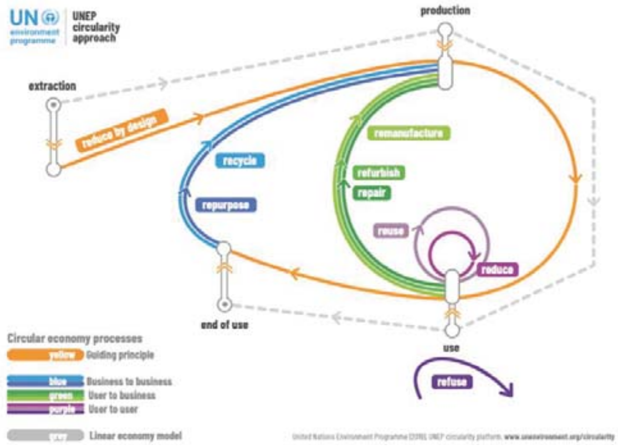

Fig.1 United Nations Environment Program Circularity Approach Framework

3 Simplified Circularity Index for Products (SCIP)

The level of circularity can be assessed using an index or a set of indicators. In the literature, several tools and indices are suggested for circularity measurement. The SCIP attempts to adopt a UN guideline for measuring sustainable development [8], which suggests that the indicator has to be simple, clear, and can be used for comparison. The framework proposed in [9] has been the background for the SCIP. The SCIP is a basic model in comparison to the Sustainable Circular Index derived in [9]. It is designed to be a starting point for industries to understand, adopt and implement circularity. The SCIP is simple enough to be adopted by both manufacturing and remanufacturing industries. The SCIP is a percentage and is expressed as an absolute number varying between zero and one hundred. Zero will signify that only new components and materials are being used, and a hundred will signify a product manufactured from only reused and recycled components and materials. With the measurement of the indicator, manufacturers will develop a basic understanding of circularity and will progress to design and manufacture more circular and, therefore, sustainable products

3.1 Simplified Circularity Index by Components

In products where individual components are being used, such as PCs, printers, or other consumer devices, the measurement framework would be at the component level

$$SCIP = \frac{Number\ of\ circular\ components}{Total\ number\ of\ components\ used}$$

3.2 Simplified Circularity Index by Weight

In products with more volumetric components, such as aluminum/steel frames, wood/metal furniture, and packaging materials, the measurement framework would be on a weight basis.

$$SCIP = \frac{Weight\ of\ circular\ components}{Total\ weight\ of\ the\ components\ used}$$

For both the above indexes, we can start with an individual product to get an indicative value on the measurement. However, to determine a broad-based measurement, the entire batch or lot needs to be incorporated into the calculation.

3.3 Case Study

A high-level study of a remanufacturing process involving PCs of a renowned brand by a well-established manufacturing partner provided the following results.

A total of 4507 devices were made available for remanufacturing. Each device was determined to contain 15 parts/ modules of significance. Out of the 4507 devices, 1291 devices were found to be beyond economical repair. However, these devices were used to repurpose 146 parts/ modules. A total of 3216 devices were fully remanufactured. To complete the remanufacture, 555 new parts/ modules were also used.

The numerator takes into account the reused and repurposed parts, apart from the new parts that were needed for the complete remanufacture. The denominator is the number of parts used in the successful remanufacturing of the 3216 devices.

In this case the resulting SCIP value was 60

The key learning from the case study was that the SCIP calculation for a new product manufactured versus the remanufactured product will vary in the determination of the numerator. In the remanufactured products, the devices beyond economical repair have to be incorporated,

4. Conclusions

Growing awareness of the climate crisis and other sustainability issues are influencing consumer expectations and behaviors. The EY Future Consumer Index found consumers willing to pay a premium for sustainable products and services will make up a third of the consumer base in 18 major markets as we move beyond COVID-19. [10]

While there have been considerable national and international effort in recent years, including ISO 14000[11], corporations are only now beginning to recognize the need to train product and manufacturing engineers in the tools and techniques of design for environment [12]. This reinforces the fact that engineers have tremendous influence on the environmental impact of products at all life stages including materials used, energy consumed, and pollution generated during manufacturing [13] By utilizing this capability, businesses can build an opportunity to create value. Companies that might have started measuring carbon savings and carbon footprints, should consider to progress to circular economy using circularity index as a key differentiator to grow revenues by aligning with the trend for sustainable consumption. This trend is likely to be accelerated post COP26 [10].

While the circularity index in this paper is a start for manufacturing companies, work is in progress to build a more comprehensive model that the manufacturing industries can adopt as they mature and progress towards a more sustainable organization.

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