Bachelor's Thesis

Circularity assessments of baseball bats

A Case Study of L-tec Sports Oy. Baseball Bats

Pawan, Kharal

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Pawan Kharal

Arcada University of Applied Sciences

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Abstract

This study investigates the circularity of baseball bats, with a particular focus on those manufactured by L-tec Sport Oy, situated at Raudoittajantie 6 Porvoo. Against the backdrop of a global shift towards sustainable practices, the circular economy stands as a promising framework to address the linear trajectory of material consumption and waste generation in traditional business models. L-tec Sport Oy specializes in fiber-reinforced baseball bats crafted from composite materials, a sector notorious for contributing to landfill waste. The research employs the Circular Transition Indicators (CTI) tool, developed by the World Business Council for Sustainable Development (WBCSD), to assess the circularity of these bats. The methodology, informed by an extensive literature review, revolves around key indicators, including % circular inflow, % circular outflow, % renewable energy, and % recovery potential. Delving into the study's boundaries, it hones in on the product-level assessment of a single baseball bat's lifecycle, considering factors such as timeframes and material inclusions and exclusions. The manufacturing process, encompassing raw material inputs, production procedures, and final outputs, is meticulously examined. Chosen indicators align with the unique characteristics of baseball bat production, ensuring a nuanced evaluation. Results indicate a current circularity level of 26.25%, revealing substantial scope for improvement. Recommendations include the adoption of bio-based resin, the use of non-virgin end caps, and the initiation of a bat retrieval program. Scenario simulations underscore the potential for achieving a circularity level of 56.26%, emphasizing the economic and environmental advantages associated with heightened circularity. In conclusion, this study not only sheds light on the circularity of baseball bats within the broader context of the circular economy but also provides actionable recommendations for L-tec Sport Oy to enhance sustainability practices in the sports equipment industry.

Keywords: Circular Economy, Sustainability, Economy, Environment, Assessment, Composite, Baseball Bats,

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Abbreviations

Circular Economy (CE)

Material Circularity Indicator (MCI)

Circular Transition Indicator (CTI)

World Business Council For Sustainable Development (WBCSD)

Glass Fiber Reinforced Plastics (GFRP)

Carbon Fiber Reinforced Plastics (CFRP)

Carbon Dioxide (CO2)

Life Cycle Assessment (LCA)

European Technology and Innovation Platform (ETIP)

Recycling and Economic Development Initiative of South Africa (REDISA)

1 Introduction

Resources available on the earth are limited. Population, economy, and industries are growing day by day which increases the demand for goods (Tansel, 2020). In the present scenario, goods are produced using raw virgin material which end up in landfill or incineration after its use. The increase in demand for resources will be fulfilled until the resources last. After everything is used, there will be no resources to build the product anymore. So, to mitigate this problem a new concept of economy developed where the linear approach of product development has changed into circular in which a product is recycled or reused after its end of life. This concept is called circular economy and it reduces waste by giving new life to the material.

The circular economy is the key to sustainability, bringing sustainable balance to the environment, society, and economy (Evans, 2023). A deep connection exists between society, the environment, and the economy. An economy cannot grow sustainably without considering the environment. Society cannot survive without the environment and the economy cannot run without society. These three elements in a balanced form are called sustainability which is described pictorially in Figure 1. A sustainable environment leads to sustainable economic growth and sustainable economic growth leads to a prosperous society.

The concept of circular economy is rising and evolving fast, particularly at a time when mankind is confronted with several concerns such as climate change, environmental destruction, and expanding socioeconomic inequality. Policymakers, manufacturers and service providers, and consumers are all working to create environmentally friendly regulations, innovate corporate methods, and shift consumer behavior toward sustainability (Islam et al., 2021). Adopting developing technology and creative business models facilitates the transition to a more circular and sustainable economy. Sustainable consumption and production power a circular and sustainable economy. The sustainability mentality, action, and behavior of stakeholders in the production and consuming ecosystem results in sustainable practices. Education is the most important engine of economic transformation because it impacts all stakeholders' thinking, actions, and behavior, including politicians, investors, researchers, educators, producers, service providers, consumers, and the media.

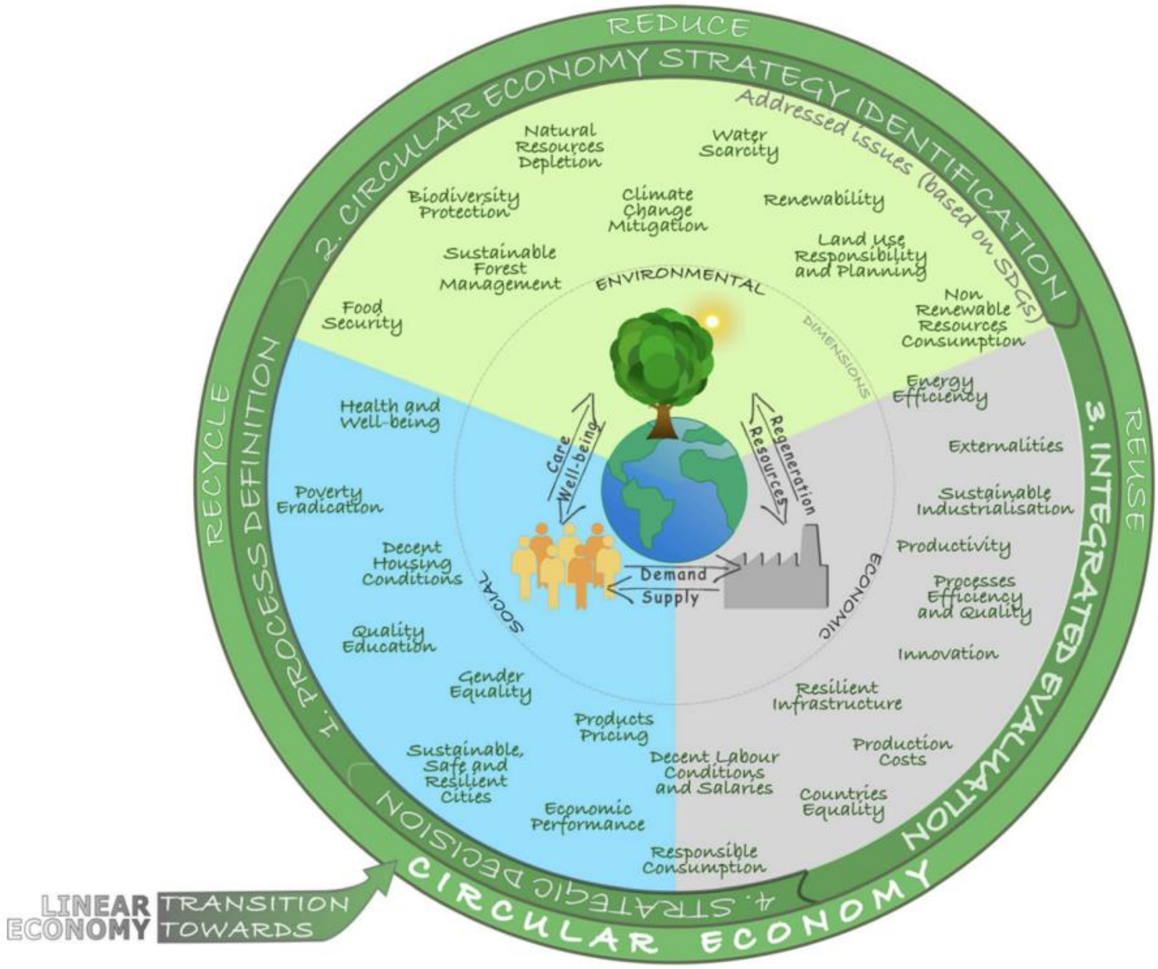

Fig 1. Sustainable CE evaluation methodology framework.(Oliveira et al., 2021)

The linear pattern of consumption should be shifted to circular. There should be a sustainable way to meet our demand and recycle after its end of life. The relationship between demand, supply, regenerative resources, consumers as well as the environment should be managed circularly. The perfect balance in all these aspects is depicted in Figure 1. This shows how the ideal world should be processed. The importance of a circular economy is enormous in the current situation where a lot of environmental and climatic problems are arising due to imbalance in nature. The circular economy is a perfect balance between all the resource hazards and the scarcity of raw materials.

1.1 Background

The circular economy is a green concept where materials are in a close loop. Most businesses in the world are on a linear path where materials are consumed to produce a product then the product goes into the hand of the customer after that the product goes to the dumping site. The value of the material is not retained and is left in a landfill. In this process, the new product will be manufactured with virgin material. In the long run, the material will completely vanish. To make the product for a long time, the resources inside the product should be recovered after its end of life.

In this study, we're going to measure the circularity of baseball bats made by L-tec Sport Oy which is located at Raudoittajantie 6 Porvoo. The company produces fiber-reinforced baseball bats with composite material.

There is a huge amount of composite waste which end up in the landfill. The value of composite fibers is not recovered which makes the composite industries linear. When the material is not in a close loop, the circularity in the product cannot be achieved (Agliardi & Kasioumi, 2023).

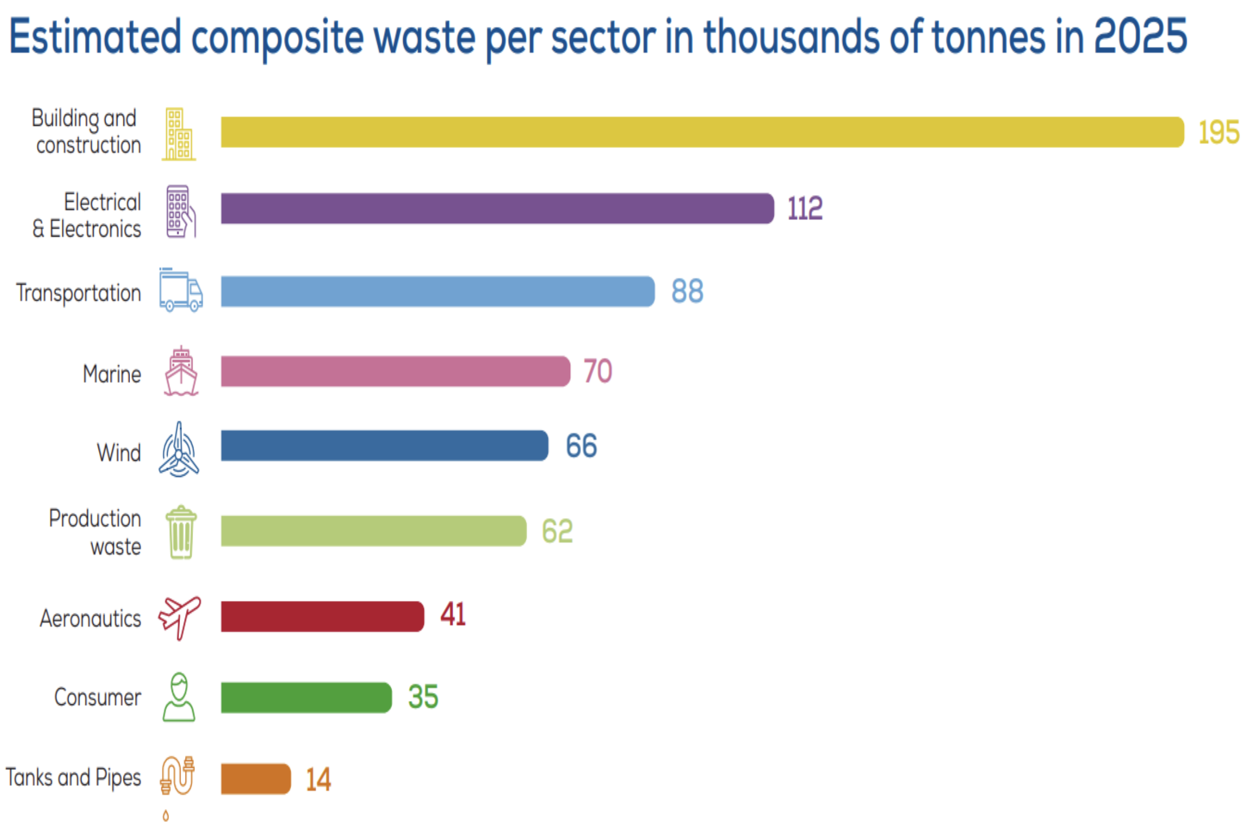

Fig 2. Composite Waste. (ETIP Wind Executive Committee How Wind Is Going Circular: Blade Recycling, 2020)

In the picture above, we can see the estimated composite waste per sector in the thousands of tonnes in 2025. The main source of composite waste is from building and construction which is equal to 195 thousand tonnes. Similarly, the electrical and electronics sector will produce 112 thousand tonnes of composite waste. Transportation will add 88 tonnes of composite waste to the environment. The marine industry which produces boats ships and fairy will add 70 tonnes of composite waste. Similarly, the wind sector will produce 66 tonnes of composite waste. Production waste will add 62 tons. Aeronautics will add 41 tonnes and the consumer will produce 35 tonnes of composite waste. The tanks and pipes will produce 14 tonnes of composite waste in 2025.

The concept of circular economy has gained significant attention in recent years, particularly in the context of sustainability and resource efficiency. In our current linear economy, resources are extracted, processed, and used to create products that are ultimately discarded as waste. This resource management approach is unsustainable and poses significant environmental challenges, including pollution, climate change, and biodiversity loss.

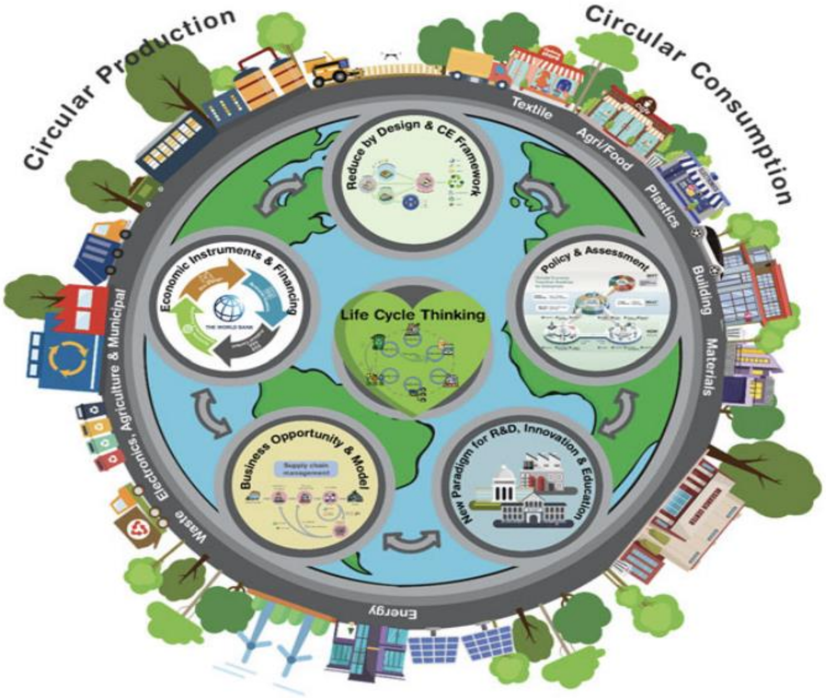

Fig 3. Infographic of Book Overview Illustrated by Sawaros Thongkaew (Liu & Ramakrishna, 2020)

Circular production, life cycle thinking, circular consumption are pillar of circular economy. These terms are self descriptionary where circular production, consumption and circular thinking of product life are seen to be crucial. From Figure 3, we can see a holistic picture of a sustainable circular economy where different circular principles are shown in a loop. Production and consumption in circular economy is only possible with support and innovation of every aspects of economy. Policy from government, incentive for circular production, awareness to consumer from media, research and development and all the essential bodies involving from raw materials to recycling cycle should be aligned within the principle of circularity. This intricate balance and understanding is essential in order to grow and thrive circular economy.

1.1.1 Research question and significance

Conversely, the circular economy aims to eliminate waste and pollution by keeping materials and resources in use for as long as possible. It is based on three principles - eliminate waste and pollution, circulate products and materials at their highest value, and regenerate natural systems. The circular economy aims to decouple economic activity from the consumption of finite resources, making it a resilient and sustainable system that benefits businesses, people, and the environment.

In the context of the sports industry, the circular economy has significant implications for producing and consuming sports equipment. As the demand for sports equipment continues to grow, there is a corresponding increase in waste generation, particularly in the disposal of end-of-life products. This is particularly true for baseball bats, which are typically made from composite fibers.

Therefore, this thesis aims to assess the circularity of baseball bats made from composite fibers. The study is commissioned by L-Tec Sports Company, a manufacturer of sports equipment, and seeks to address the following research questions:

What is the degree of circularity in Baseball Bats produced by L-tec Sport Oy?

How can the circularity of baseball bats be improved?

1.1.2 Scope and Thesis Structure

The scope of the study is limited to baseball bats made from composite fibers and epoxy resin, and the research will focus on assessing the circularity of the product through different circularity indicator calculations. The significance of this study lies in its potential to contribute to the development of a more sustainable and circular sports industry. The study aims to provide insights into the circularity implications of using composite fibers and epoxy resin in the production of baseball bats and identify opportunities to improve the circularity of the product.

2 Literature Review

2.1 Concept of Circular Economy

The circular economy is a new concept that helps to transform the linear approach of material use into a circular path. In a linear economy, raw virgin material is taken from the environment, and the product is manufactured. After the end of the life of that product, it is dumped into a landfill. A new product is used after the last one is replaced. In this cycle, the material from the environment will continuously decrease and the size of the landfill will continuously increase. Ultimately, we will reach a point where there will be piles of waste in landfills and a scarcity of resources to make a new product. The circular approach helps to recover value and material after the end of the life of that product.

'Rather than using eco-efficiency to try and minimize material flows, eco-effectiveness transforms products and related material flows to support a workable relationship between ecological systems and economic growth. Instead of reducing or delaying the cradle-to-grave flow of materials, eco-effectiveness creates metabolisms where materials are used over and over again at a high level of quality.' Michael Braungart (Macarthur, n.d.).

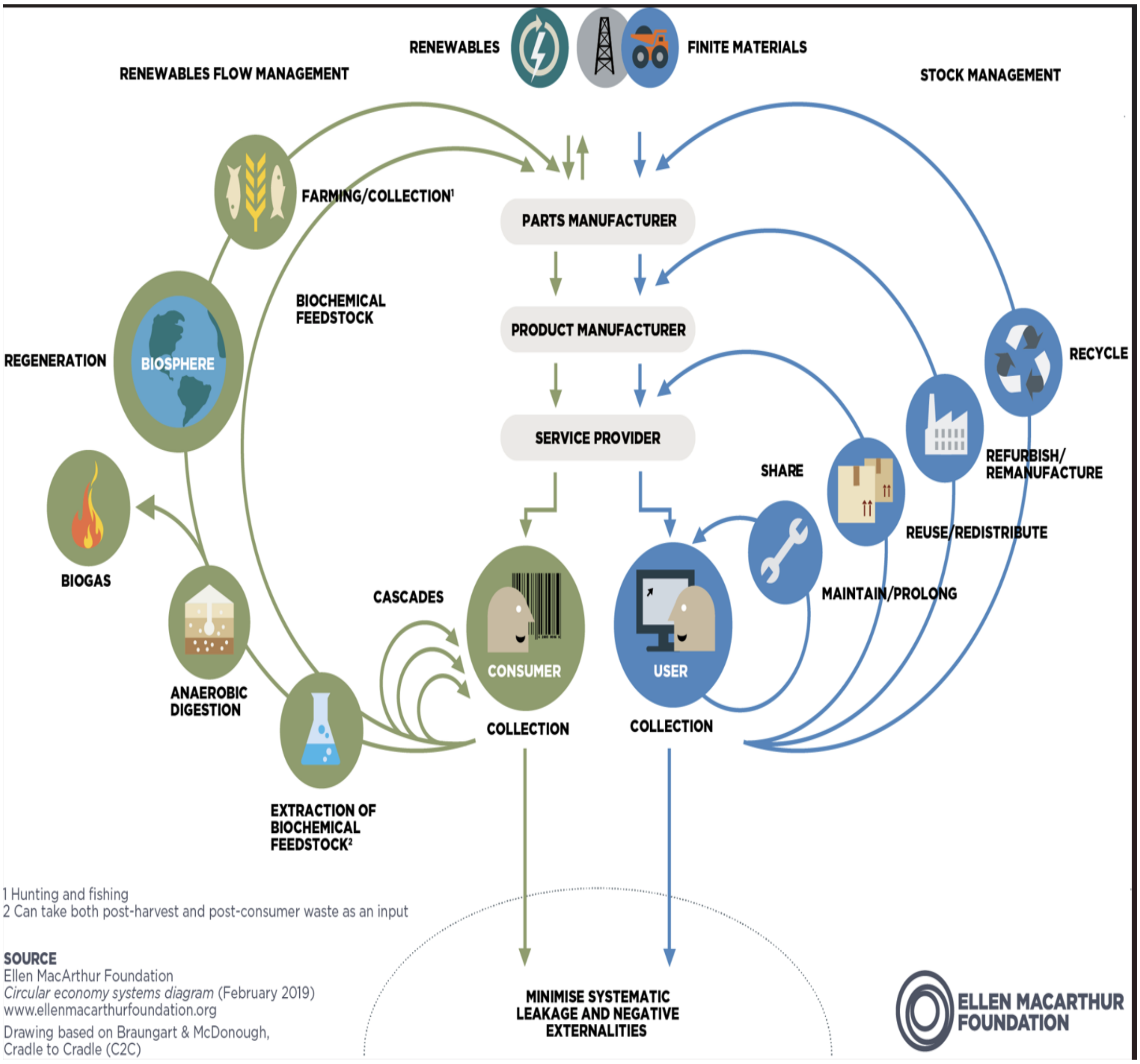

Fig. 4 Circular economy systems (Circular economy systems diagram (Source Ellen MacArthur Foundation, 2019)

There are different ways to make the resources in a cycle. Most of the ways are described in the figure 4.

2.1.1 Share

Sharing products helps to do work without owning the product. This method saves money and does work for everyone. This type of method works effectively when we share some product in a community or society. For example, if one community has a big lawn mower then the entire community can cut grass without bearing the whole price of the mower. Everyone can

rent or use the service with a small amount of money. This method saves money for the whole community and the product will be used at its highest usage. The collected fee can help to maintain the product for its smooth functioning.

2.1.2 Maintain

When a product faults then we can maintain and restore its value. For example, if one of the tires of our car is deflated, then we repair it and inflate it again. We never buy a new car for this kind of issue. Similarly, for smaller or bigger products we can find a way to maintain their function and make their life longer.

2.1.3 Reuse

All of us buy groceries for everyday life. We need some sort of bag to carry our items. Most of the time it is a polyethylene bag that we can easily and cheaply get in grocery stores. In every household, we can find single-use plastic bags which are dumped after it's used for a time. We can reuse that bag again and again until it breaks. This is one of the ways to be more circular in our everyday life. (Potting et al., 2017)

2.1.4 Redistribute

In a circular economy, redistribution means putting resources, goods, or materials that would normally be thrown away back into the economy for reuse or recycling. This may be achieved through a variety of strategies, including repurposing and reselling used items, creating closed-loop supply networks, and creating new products utilizing recycled resources. Redistribution can assist to eliminate waste, lessen negative environmental effects, and encourage sustainability by extending the time that resources are in use. A circular economy can also help us build a more just system that supports regional communities and lessens socioeconomic inequities. In general, redistribution is crucial to building a more sustainable and prosperous future for everyone and is a fundamental tenet of a circular economy. (Potting et al., 2017)

2.1.5 Refurbish

When a product loses its functioning due to some faulty components but the product has the potential to regain its life then the product is repaired with parts replacement. The process of repairing the product and reselling it to market is called refurbishment. In this process, the cycle of the product elongates and makes it more circular in terms of the circular economy. (Potting et al., 2017)

Different companies refurbish and resell the product. The most commonly refurbished items are mobile phones, TVs, and other electronic equipment.

2.1.6 Recycle

Recycling is the process of sending the product to a recycling plant where the materials of products are sorted and again sent to the manufacturer for producing the same product. There is huge potential and market in this area. Most of the circularity principle focuses on recycling the product and closing the loop. If a material can be reused as material for the same or similar product then the system can be considered completely circular. (Potting et al., 2017)

Product recyclability is one of the most important parts of a circular economy. The recyclability capabilities of the product will determine how circular the product is.

Aluminium is one of the most recycled materials where 43 to 70% of new material comes from recycling because of its easy recyclability nature. Aluminum can be melted and molded more easily than other metals making it a more sustainable and circular material. End-of-life recycling rates for other significant non-ferrous metals (such as copper, zinc, and magnesium) are lower, for example, copper is 43 to 53%, zinc 19 to 52%, magnesium 39%. (Macarthur, n.d.)

2.1.7 Life Cycle Assessment (LCA) and Circular Economy (CE)

Life Cycle Assessment (LCA) and Circular Economy (CE) are synergistic pillars driving the transition towards a more sustainable and regenerative paradigm. The Circular Economy represents a shift away from the traditional linear economic model, emphasizing the creation

of a regenerative closed-loop system. In this innovative framework, products are designed for longevity, easy repair, and the ability to be repurposed or returned to nature without generating pollution or greenhouse gas emissions (Kirchherr et al., 2023). LCA, on the other hand, serves as a crucial analytical tool within the Circular Economy, providing a quantitative methodology to assess and estimate environmental impacts throughout a product or service's life cycle (De Luca Peña et al., 2022). By identifying impact hotspots and establishing a baseline for improvements, LCA supports the optimization of resource use and facilitates informed decision-making, aligning seamlessly with the principles of the Circular Economy. Together, LCA and CE contribute to a holistic approach that promotes sustainable practices, minimizes waste, and fosters the transition towards a circular and regenerative economic model.

2.2 Circular Economy Principles

2.2.1 Closing the material loop:

Closing the loop is the main strategy of the Circular Economy, embodying a commitment to sustainable practices where resources are continually recycled and repurposed. Reverse logistics of end-of-life products plays a vital role in the circular economy and helps to rebuild the whole system of products with minor changes and gives a new life to the product (Mallick et al., 2023). Barloworld, a South African industrial conglomerate, exemplifies this concept through the operation of the second-largest Caterpillar equipment remanufacturing plant globally, minimizing waste and extending the life of components (Kaleidoscope Futures Lab, 2018). Similarly, Dutch Awearness, a pioneer in circular textiles, contributes to closing the loop by designing recyclable workwear and suits, ensuring that products can be transformed into new resources rather than becoming waste (Siderius & Poldner, 2021). This commitment to closing the loop reflects a forward-thinking approach, reshaping consumption patterns and fostering a circular economy that prioritizes resource efficiency and environmental sustainability.

2.2.2 Measuring Circularity

Everything needs to be quantified in order to get realization of intensity. Measuring circularity in today's society, where the linear economy conflicts with numerous environmental, social, and economic challenges, is imperative for a successful transition towards a Circular Economy.

Policymakers and the research community prioritize the adoption of the Circular Economy model, aligning with initiatives such as the European Union's Circular Economy Strategy, the European Green Deal's commitment to carbon neutrality by 2050, and the United Nations' Sustainable Development Goals (SDGs). The transformation from conventional to circular business models involves technological shifts, emphasizing strategies like refuse, reduce, and recycle. To ensure a beneficial transition, it is crucial to monitor Circular Economy performance through quantitative measures. Key tools for quantifying circularity include Key Performance Indicators, Life Cycle Analysis, Material Flow Analysis, and quality protocols such as ISO/TC 323. These tools facilitate the measurement of Circular Economy performance in urban and industrial settings, supporting decision-making for policymakers and CEOs. (Papamichael et al., 2023)

2.2.3 System thinking

System thinking, a cornerstone of Circular Economy principles, involves a comprehensive understanding of the intricate relationships and interdependencies within a system. Companies embracing this approach prioritize a holistic view of their operations, recognizing that every component of a product's lifecycle is interconnected. Biogen, a UK renewable energy company, exemplifies system thinking by deriving both energy and bio-fertilizer from food waste, demonstrating how waste can be transformed into valuable resources within a closed-loop system (Veleva et al., 2017). Similarly, Interface®, a U.S. carpet manufacturer, adopts system thinking in its Mission Zero strategy, aiming to eliminate negative environmental impacts by considering the entire lifecycle of their products. This approach not only minimizes waste but also fosters sustainability by addressing the complex dynamics inherent in the production and consumption of goods.

2.2.4 Maximize value

Maximizing value is a key principle in Circular Economy, emphasizing the extraction of the highest possible utility and worth from resources throughout their lifecycle. Companies that prioritize maximizing value seek innovative ways to use, reuse, and repurpose materials, minimizing waste and environmental impact. Biogen, a UK renewable energy company, exemplifies this principle by generating both energy and bio-fertilizer from food waste, showcasing how waste materials can be transformed into valuable resources within a closed-loop system (Veleva et al., 2017). By adopting strategies that enhance the utility and lifespan

of products, businesses contribute not only to environmental sustainability but also to economic efficiency, creating a more circular and resilient approach to resource management.

2.2.5 Collaboration:

Collaboration is a key strategy demonstrated by REDISA, a South African tire recycling project (Sebola et al., 2018). This initiative empowers entrepreneurs along the used tire value chain, emphasizing not only environmental benefits but also economic empowerment through collaborative efforts.

2.2.6 Renewable energy sources:

Renewable energy sources play a pivotal role in achieving circularity, as seen in Biogen's commitment to sustainable energy solutions (Veleva et al., 2017). This showcases the integration of renewable energy into operations, aligning with circular economy principles.

2.2.7 Positive footprint

Novamont, an Italian bio-plastics company, showcases a positive environmental footprint. Renowned for producing compostable coffee capsules, Novamont exemplifies how products can leave a positive mark on the environment, aligning with circular economy principles (NOVAMONT, 2021).

2.2.8 Strong Sustainability

Sustainability is crucial in any institution from long term survival. It gives long term vision as well as nurture the foundation of any institution with good motive and inspiration. Dutch Awearness, a pioneer in circular textiles, embodies the principles of strong sustainability and future-based orientation. Their recyclable workwear and suits showcase a commitment to building a future where products are designed with recyclability in mind, contributing to a circular and sustainable vision (Siderius & Poldner, 2021).

2.2.9 Future-based Orientation

A future-based orientation is a guiding principle in Circular Economy that underscores the importance of designing products and processes with a long-term vision for sustainability. Companies embracing this principle anticipate and mitigate potential environmental and social

impacts by considering the entire lifecycle of their products. Dutch Awearness, a pioneer in circular textiles, exemplifies future-based orientation by designing workwear and suits that prioritize recyclability (Siderius & Poldner, 2021). Their commitment reflects a forward-thinking approach, envisioning a future where products are not only functional but also environmentally responsible. This orientation encourages businesses to proactively address challenges associated with resource depletion and waste, fostering a mindset that prioritizes the well-being of both the planet and future generations. By planning for a sustainable and circular future, companies contribute to a more resilient and responsible global economy.

2.2.10 Resilient System:

Resilient systems are exemplified by Interface®, a U.S. carpet manufacturer with the Mission Zero strategy. This ambitious goal aims to eliminate negative environmental impacts, showcasing resilience in adapting processes and products to align with circular economy principles.

2.3 Waste Hierarchy

This model focuses primarily on the value chain's end stages, which entail recovering materials and resources from goods that are no longer useful in their current application. The ultimate objective is to reuse the recovered resource in such a manner that its maximum potential value is maintained for the longest feasible period. One of the best chart for waste hierarchy is shown in Figure 5. Steel salvaged from a car, for example, can be reused or upcycled in higher-value applications rather than being downcycled into lower-value items. Companies should address the "hierarchy of waste" and strive for closed-loop solutions when discovering methods to produce value from end-of-life items, even if they are complicated and not always technically viable. Reduced material quality solutions should only be chosen as a last option. (Lacy et al., 2020)

Fig 5. Hierarchy of waste from a circular economy point of view (Lacy et al., 2020)

2.4 Framework for the company for Circular Economy Adaption

Customers are essential to the circular economy because they promote organizational development, sustainability, trust, and profitability. The resources and talents that firms require to accelerate expansion and satisfy consumer expectations are referred to as "fuel for growth." By designing more ecologically friendly goods and services and creating more effective supply chain procedures, a focus on circular economy concepts may aid businesses in growing these resources and skills.

For businesses to remain competitive and adjust to shifting client expectations, they must exhibit competitive agility. Organizations may create more sustainable goods and processes, set themselves apart from competitors, and react more swiftly to shifting customer requirements by adopting the concepts of the circular economy. In turn, this may promote expansion and profitability.

Fig 6. Competitive Agility Framework (Lacy et al., 2020)

A license to grow is the approval that businesses acquire from clients, authorities, and other interested parties to keep growing their businesses. The intricate balance between all the aspects of the company with sustainability, profitability, and growth is shown in Figure 6. Organizations must show a commitment to sustainability and develop trust with their clients and other stakeholders to be granted permission to expand. Organizations may establish a reputation as reliable and responsible firms, which can support a license to expand, by adopting the concepts of the circular economy and implementing sustainable business practices.

A business that has won the trust and loyalty of its clients and other stakeholders can be trusted. Organizations may gain the trust of their consumers and other stakeholders by embracing the concepts of the circular economy and exhibiting a dedication to sustainability. This may support long-term sustainability and profitability goals while also attracting new consumers and keeping existing ones, which can assist in spurring growth and profitability.

3 Methodology

In assessing tools for product-level circularity, several options were considered, for example Circulytics by the Ellen MacArthur Foundation, CIR Celligence by Boston Consulting Group, Material Circularity Indicator (MCI) by Ellen MacArthur Foundation and Granta Design, Circulator by EIT RawMaterials, and Circularity Calculator. (Chrispim et al., 2023) While each tool offers unique features, the decision to utilize the Circular Transition Indicators (CTI) tool was driven by several factors. CTI's collaborative development involving industry partners, academia, and diverse organizations ensures a comprehensive and inclusive approach (WBCSD, 2022). Its seven-step self-assessment method, coupled with a specific focus on product-level circularity indicators, distinguishes CTI for its detailed coverage. The global adoption by approximately 2000 organizations across 94 countries underscores its widespread acceptance. In comparison to other tools, CTI's flexibility in assessing circularity at various organizational levels and its detailed focus on circularity dimensions specific to products provided a more tailored and nuanced evaluation approach, aligning closely with the objectives of the product-level circularity assessment in question.

3.1 Procedure

For measuring the circularity of baseball bats, a product-level circularity analysis is carried out using the Circular Transition Indicators (CTI) tool. This tool was developed by the World Business Council For Sustainable Development (WBCSD). The organization is led by CEOs of over 200 international companies and works to limit climate crisis, restore nature, and tackle inequality which helps people to thrive sustainably. The tool developed by WBCSD helps companies calculate their circularity in product and business.

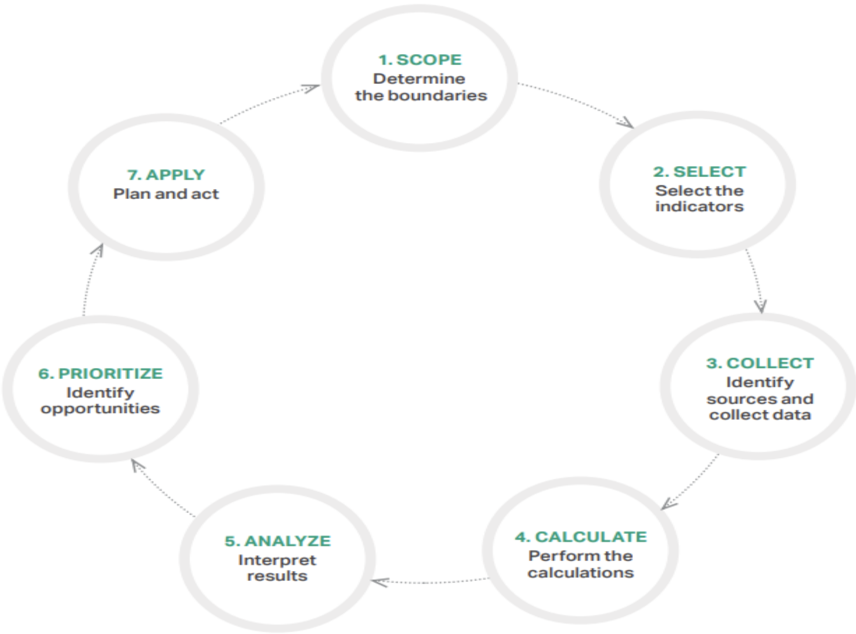

Fig 7. Process cycle (WBCSD, 2022)

The organization helps companies to evaluate and improve the circularity of the company. The CTI tool helps to simplify the calculation process and gives ways to improve it. The process involves a cycle as shown in figure 7. Firstly, the set of boundaries needs to be set to see a clear image of the company target regarding circularity. So in initial step is to determine the boundaries. After that, assessment methods need to be selected. For example, to calculate the circularity of brick, most parameters to measure the circularities are compelled within the manufacturing process. To make a brick, soil, water, and heat are required primarily. In this case, the material circularity index should be assessed for soil, water circularity for water consumption, and the sustainable energy ratio for heat. After collecting all the necessary process details, quantitative data should be collected for every input variable as well as for output products and bi-products. In the fourth step, calculations need to be done to see how circular the product is. After that result should be carefully analysed and then processed to prioritize the action which will increase the circularity of the product. In the final stage, the outcome and suggestions from the result should be understood and applied correctly.

3.1.1 Define the scope

Any calculation and study have boundaries. Without it, the result will not be accurate and precise. For this study, there are some boundaries and limitation that needs to be considered during the calculations. Boundaries and limitations provide more realistic and genuine results. For the circularity study of baseball bats, we need to make some boundaries to some extent that we can measure efficiently and with higher accuracy.

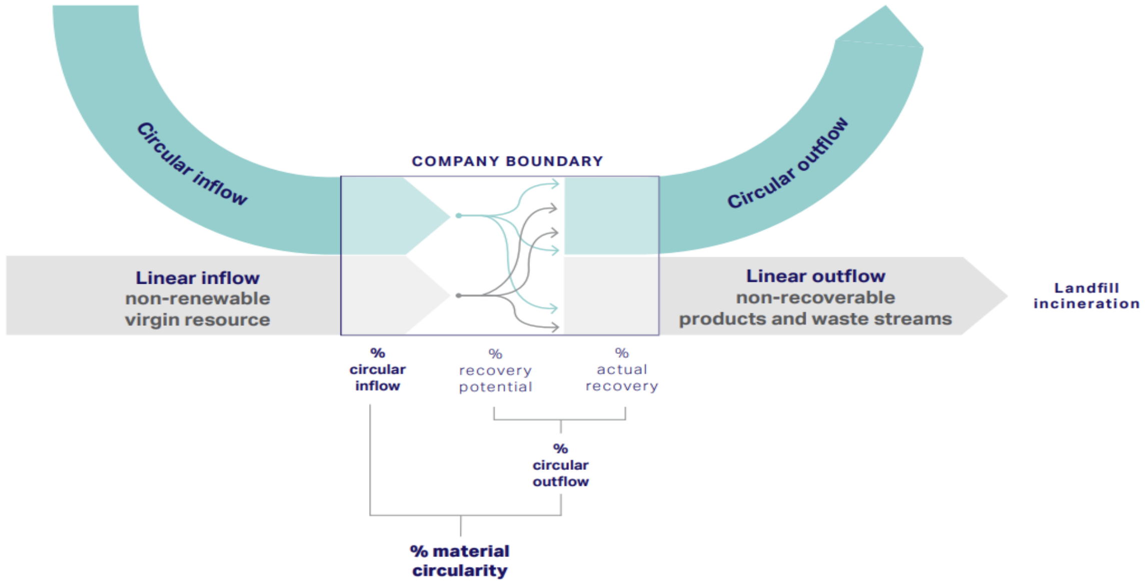

Fig 8. Material flow (WBCSD, 2022)

To clarify the definitive scope of the study, the manufacturing procedure, raw material input, and output of the process should be studied in depth. In this study, a baseball bat produced by L-tec Sport Oy which is shown in Figure 11 is evaluated and its circularity is assessed throughout the process of manufacturing the baseball bats. Fibre and resin are combined in a specific machine with all required parameters as shown in Figure 9 . Fibers are pulled out from different bundles dipped into a resin bath and then winded in a rotating device.

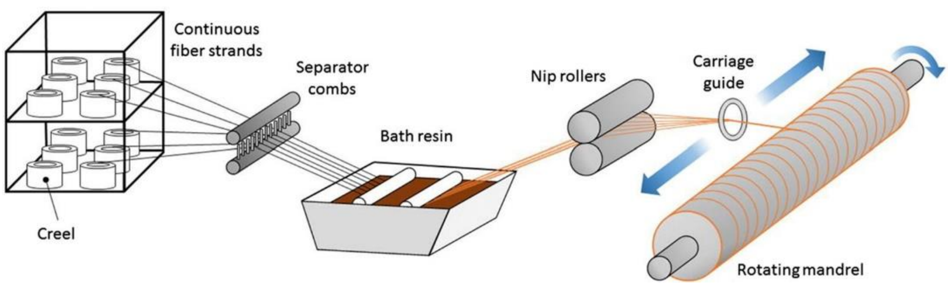

Fig 9. Filament Winding Process. (Shrigandhi & Kothavale, 2021)

The actual process of manufacturing in L-tec Sport Oy is shown in Figure 10. For the definitive assessment, circular input, circular output, manufacturing process, linear input, and output need to be considered appropriately. The pictural representative of these variables in the definitive process is more clarified in Figure 8.

Fig 10. Manufacturing of Baseball Bat At L-tec Sport Oy.

Fig 11. Baseball Bat Manufactured By L-tec Sport Oy.

Defining Boundaries of the Study

1. Level of Business: Product level assessment of a single product i.e Baseball Bat
2. Timeframe: One product cycle i.e. resources taken to produce one single bat.
3. Inclusion and exclusion: Including everything in a study is an excellent way to assess any data but gathering all data on everything is extremely difficult. Some flexibility in materials inclusion and exclusion helps to get good results more conveniently but also reduces the accuracy of the study. Therefore in this study, all the possible material data

were included, and minor difficult materials were excluded. All the materials make it difficult to get data. Some play a significant role in the product and some are finishing materials. So it is very crucial to include important material. Table 1 shows all the materials that are required to produce a final product as shown in Figure 11 with details of material included or excluded for calculation with appropriate reason.

Table 1. Material list with inclusion and exclusion for study.

Material	Inclusion/Exclusion	Reason
Fibers	Included	A large portion of the Product
Resin	Included	A large portion of the Product
Baseball bat cap	Included	Significant weight on the product
Dyes	Excluded	Insignificant weight
Packaging	Excluded	Is not contained inside the main product
Grip Tape	Excluded	Lack of information

3.1.2 Indicators selection

The selection of indicators plays a significant role in the calculation of circularity. For this particular study, certain indicators are selected that covers significant process in the manufacturing process of baseball bats. Indicators selected for the study are listed below with their descriptions.

For this study, the following indicators are selected in the CTI tool framework.

1. % circular inflow
2. % circular outflow
3. % renewable energy
4. %recovery potential

There were other indicators which were not selected for this study. The indicators that were not relevant for this study such as water circularity are not included because there is no water use in the manufacturing process of the bats. Similarly, the critical materials indicator was not selected because no critical material was used in the production process.

3.1.3 Data Collection

Data collection is a crucial and most important part of any study. In this study, all the data related to the product were taken from respective sources. Most of the data was obtained from Ltec Sport Oy. Different indicator requires different data and information. For the circular inflow indicator, all the possible data of raw material and its source was obtained which is tabulated in Table 2.

Table 2. Material required to manufacture one bat

Material	Weight(g)	Material specific	Source type
Fiber	161g	Glass Fiber	Virgin
Resin	484 g	Proset Epoxy	Virgin
End Cap	24 g	Acrylonitrile butadiene styrene (ABS)	Virgin
Total material weight	669 g		
Waste	110 g		

For the circular outflow indicator, product and production waste for specific products was calculated.

The final weight of Bat: 600 g

Total composite waste: 110 g

For renewable energy indicators, the amount of energy required to produce a bat was calculated. The electricity source of the factory was the national grid of Finland. For this calculation, one month of electricity consumption was evaluated when the other production system was closed. By running only baseball bat production, 3000 kWh of electricity was consumed in a month with the production volume of 1000 bats. This data was only from production machines which excludes the factory usage like heating, ventilation, and lighting.

So, one bat production required 3 kWh of electricity.

3.1.4 Calculation

Different indicators have different ways of evaluating their values. CTI tool uses percentages for every indicator value which makes it easier to compare the results. Data and information accuracy are crucial for any calculation. The calculations made in this study are done in a precise and effective way to get accurate results. For the calculation of circularity, different indicators were evaluated. The formula and procedure to calculate the results are given below with their respective indicators. Material circularity indicator or main circularity indicator is the average of circular inflow and circular outflow.

i.e

$$Material\ circularity(\%) = \frac{\%cicular\ inflow + \%circular\ outflow}{2}$$

1. % circular inflow

For calculation of circular inflow %, the following equation is used

$$\frac{\begin{array}{c}((\text{\% circular inflow A} * \text{ mass A})\\ + (\text{\% circular inflow B} * \text{ mass B})\\ +(\text{\% circular inflow C} * \text{ mass C})\end{array}}{Total\ mass\ of\ all\ inflow\ (A+B+C)}$$

2. % circular outflow

For calculation of circular outflow %, the following formula is used.

$$\frac{\begin{array}{c}((\text{\% circular outflow D} * \text{ mass D})\\ + (\text{\% circular outflow E} * \text{ mass E})\\ +(\text{\% circular outflow F} * \text{ mass F})\end{array}}{Total\ mass\ of\ all\ outflow\ (D+E+F)}$$

3. % renewable energy

For the calculation of % renewable energy, the following formula is used.

$$= (\frac{total\ renewable\ energy\ consumed * 100\%}{Total\ energy\ consumed})$$

4. %recovery potential

Recovery potential is the quantitative potential of a product that can go for another cycle after the end of its first cycle life. So, it is assessed by measuring the potential of recovery after the end of life.

The rule for % recovery potential X

Can the material be recovered? = YES - full potential= 100%

NO - no potential = 0%

some potential = X%

or % biodegradable

4 Results and Discussion

The circularity of baseball bats produced by L-tec Sport Oy was evaluated using the Circular Transition Indicators (CTI) tool. This tool was developed by 30 global companies through WBCSD Circular Economy program . Globally, this tool has been used over 94 countries and by more than 2000 companies. This method is employed by various companies globally such as Whirlpool cooperation, BP, Microsoft, Aptar, DB etc. This assessment focused on the product-level circularity analysis of baseball bats, considering key indicators such as % circular inflow, % circular outflow, % renewable energy, and % recovery potential.

4.1 Circular Inflow:

The calculation of % circular inflow involved considering the circularity of each input material (A, B, C) weighted by their respective masses. All the material used in production was virgin so the circular inflow for baseball bats is 0%.

The circular inflow of the product is minimal. This can be improved in the following ways:

1. Utilizing the bio-based resin which meets product requirements. For example, Proset® M1052 LAM-237 contains 34% bio-based content. This will improve 6.26% circularity in circular inflow. Hardener is not bio based so when mixing resin and hardener, total bio based contains become 26%.
2. By using non-virgin end cap ABS plastics, circularity inflow can be further improved from 6.26% to 9.84% including the bio-based resin.

In this way, the current linear inflow can be made circular as much as possible for L-tec Sport Oy. Additionally, research and development should be considered in searching for higher circular and efficient fiber resin system.

4.2 Recovery Potential:

The % recovery potential assessed the quantitative potential of the baseball bat to undergo another cycle after its initial life. This was determined by considering whether the material could be recovered. The rule for % recovery potential was applied based on the recovery potential after the end of the product's life.

According to Kuusakoski Recycling Center, all the composite materials are recycled and sent to cement making process where the whole material is utilized. This means that 100% of the material is used in another cycle again. In this way, another loop is started where it is again considered as recycled raw material. Since baseball bats are made up of composite material and ABS plastics which can be recycled. Therefore, the recovery potential of the product is 100%.

4.3 Circular Outflow:

For outflow, currently production waste is sent to the Kuusakoski recycling center for recycling. Baseball bats are not recovered or retrieved by the company. so there is no evidence of the recycling of bats from the company. According to municipal recycling rate of Finland, 49% of all solid waste goes to recycling (HSY, 2022). Therefore, the circular outflow for baseball bats is 56.9%.

Currently, 110g of waste per bat is sent to Kuusakoski for recycling. Kuusakoski, a company specializing in composite waste processing, employs an approach to ensure maximum utilization. The waste, including materials like glass fiber-reinforced plastics (GFRP) and carbon fiber-reinforced plastics (CFRP), undergoes a comprehensive treatment. Initially, the waste is cut into smaller pieces, shredded into homogeneous particles, and then sent to their cooperation partner, Finnsementti. In collaboration, the polymer component is utilized as energy, replacing fossil fuels, while the fibers serve as raw materials in cement production. The high-temperature treatment at 1500 degrees Celsius ensures the fibers transform into minerals, contributing to significant carbon dioxide(CO_2) emission savings. Kuusakoski is committed to recovering 100% of the materials received, and while their current process is uniform for various composites, they express interest in exploring specialized treatment options for high-value materials like carbon fiber. Additionally, their upcoming facility in Hyvinkää, set for completion in 2024, will enhance waste treatment efficiency and incorporate advanced dust

suppression systems, emphasizing their dedication to circularity and sustainable waste management practices.

For more circular outflows, the company can launch a program to retrieve its baseball bats after the end of life from customers with some user-friendly benefits for the next purchase. In this way, the company can get more customer retention as well as help to get the company more circular. If the company could retrieve all the bats then the circularity of outflow would reach 100%.

4.4 Renewable Energy:

The % renewable energy indicator was calculated by evaluating the amount of energy required to produce a baseball bat. The formula used was based on the electricity consumption for bat production, considering the energy source from the national grid of Finland with 100% renewable suppliers. So, the renewable energy of baseball bats is 100%.

4.5 Scenario Simulation

The circularity of baseball bats produced currently is 29.3%. Currently circular inflow level is at 0% and outflow is at 56.9% which can be seen in Figure 12. The potential for improvement is high. Circular inflow and outflow will lead to greater circularity for the company. The improvement in circularity will increase the company's profile towards sustainability and help to get more customers. The following measures will increase the circularity of baseball bats up to 56.26.% as shown in figure 13.

1. Using Bio-based resin.

2. Using non-virgin endcap.

3. Retrieving possible bats from the end of life from the user.

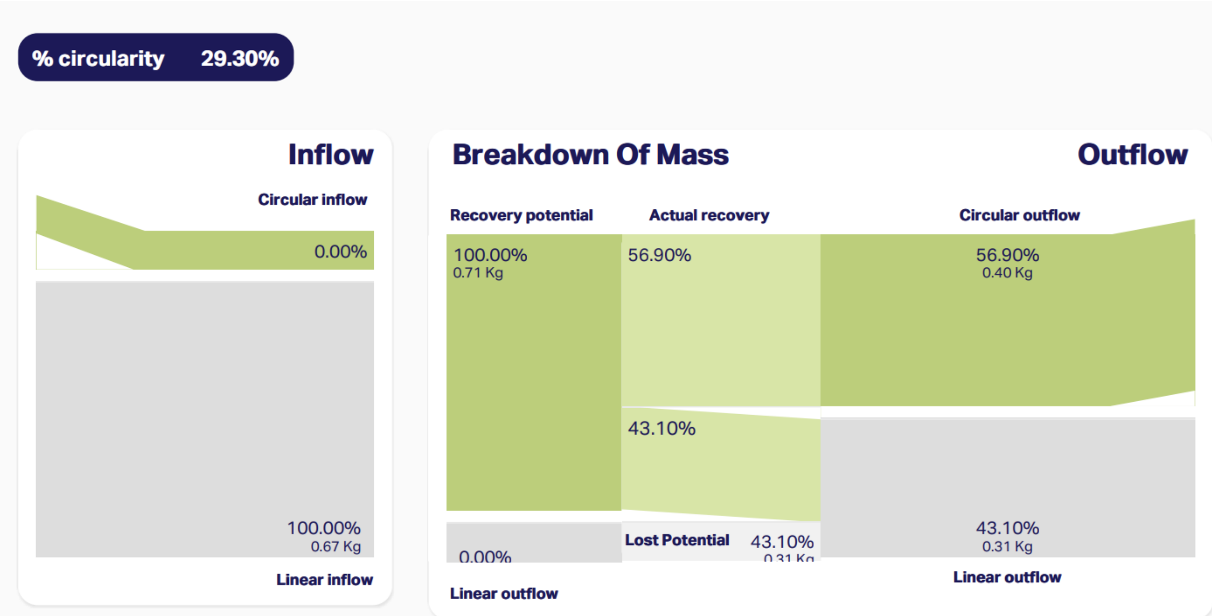

Figure 12. Current Circularity Value from CTI tool.

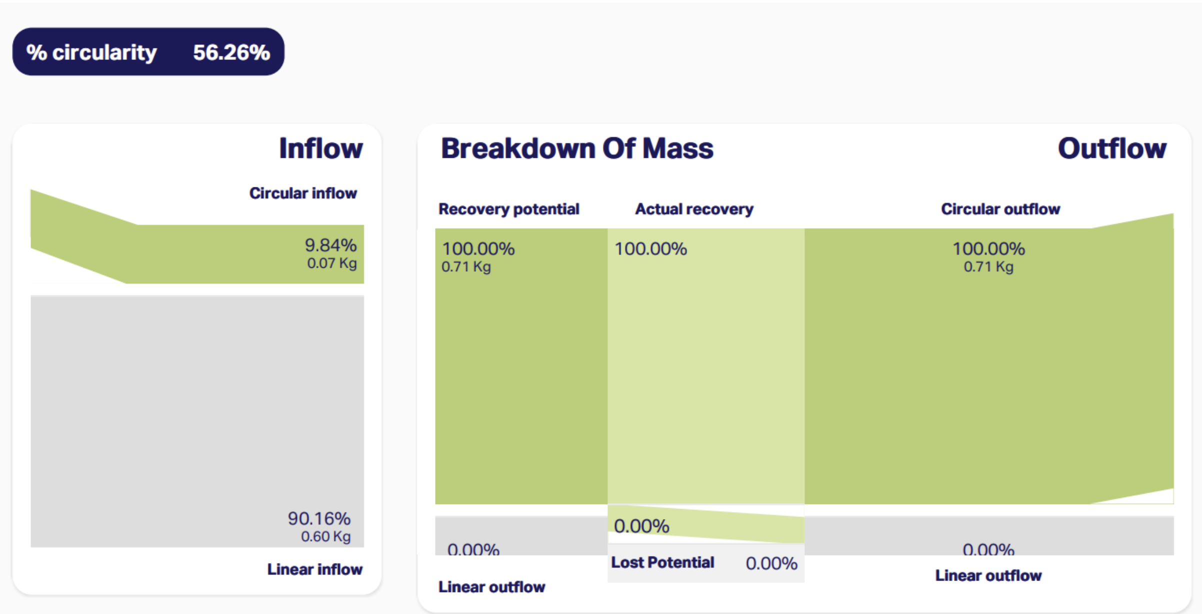

Fig. 13. Possible circularity value from CTI tool.

5 Conclusion And Recommendations

In conclusion, the circularity assessment of baseball bats produced by L-tec Sport Oy, using the Circular Transition Indicators (CTI) tool, reveals valuable insights into the product's sustainability. The study focused on key indicators such as % circular inflow, % circular outflow, % renewable energy, and % recovery potential. The analysis provided a comprehensive understanding of the current state of circularity and identified areas for improvement.

The current circularity of baseball bats stands at 26.25%, with a circular inflow of 0%, circular outflow of 56.9%, and renewable energy at 100%. The assessment also highlighted a 100% recovery potential, indicating the recyclability of composite materials used in bat production.

Recommendations:

1. Bio-based Resin: Introducing bio-based resin, such as Proset® M1052 LAM-237 with 34% bio-based content, can significantly enhance circular inflow from 0% to 6.26%. This innovation can contribute to a more sustainable material lifecycle.
2. Non-virgin End Cap: Incorporating non-virgin end cap materials, such as ABS plastics, further improves circular inflow to 9.84% from 6.26%.
3. End-of-Life Retrieval Program: Implementing a program to retrieve baseball bats from customers at the end of their life cycle can boost circular outflow. By partnering with customers and providing incentives for bat return, the company can increase circular outflow from 56.9% to 100%.

Scenario Simulation:

A scenario simulation demonstrates the potential circularity improvement, projecting an increase from the current 26.25% to an impressive 56.26%. The combined impact of bio-based resin, non-virgin end cap, and end-of-life retrieval program significantly elevates the circularity profile of baseball bats.

By embracing these recommendations, L-tec Sport Oy can not only enhance the environmental sustainability of its baseball bat production but also position itself as a leader in circular

economy practices. This approach aligns with the global trend towards more sustainable and circular business models, appealing to environmentally conscious consumers and contributing to the broader goal of achieving a circular and regenerative economy.

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