# Approach to Analyse Sustainable Manufacturing Performance at the Production Line and Plant level

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***Abstract*-The next step in the evolution of manufacturing will be the implementation of flexible, scalable systems that produce a product in the most favorable environment using the best available tools, techniques, and resources to achieve significant cost savings, increased productivity, and long-term benefits. Through a review of relevant literature and a series of case studies, this study assessed the efficiency of sustainable manufacturing at the plant and line levels.The study's basis was the influence of economic, social, and environmental aspects on manufacturing sustainability. Discussions on the fundamental approaches for analysing the performance of sustainable manufacturing at various production levels had taken place throughout the research. This study also extensively analysed the approaches currently used to analyse sustainable manufacturing performance, and it explored and examined the challenges encountered. These approaches are addressed in this study through a case study of a recycle-friendly automotive aluminium alloy business and production of carbonated bottled drinks. The framework is then used to suggest a thorough set of approaches for analysing sustainable manufacturing at the plant and production line levels.**

***Keywords*: sustainable manufacturing, integrated techniques, 6Rs Concept, microbiological prefiltration, Performance evelauation**

## I. INTRODUCTION

Sustainable manufacturing, according to the US Department of Commerce, is the creation of manufactured items using techniques that limit negative environmental repercussions, conserve energy and natural resources which are safe for employees, communities, and consumers, and are economically rational. Reduced environmental impacts, improved energy and resource efficiency, minimal waste generation, and operational personnel health while maintaining or improving product and process quality with overall life-cycle cost benefits are required for sustainable manufacturing at the product, process, and system levels [1]. Industrial output ought to be eco-friendly, and manufacturers must practice conscientious resource management [2], contends that environmental rules are frequently considered as a "must," resulting in larger design constraints and additional expenditures. Several distinctive features of manufacturing activities, as discussed in [3], may allow the manufacturing sector to make significant contributions to the advancement of sustainability. Businesses now have a responsibility to lessen their adverse effects on the environment because of the critical need to address the worldwide environmental crisis. Adopting sustainability objectives and practices boosts a company's capability to withstand environmental deterioration, according to these sectors. In particular, businesses have started tracking sustainability indicators to evaluate their performance on the sustainability front and include hard numbers into their decision-making processes. Carbon Effective technology and circular solutions are largely considered as the future of the industrial sector, which is committed to becoming more sustainable while boosting productivity, quality, and supply. As stated in [4], a variety of life-cycle concepts should include the 6R concept (reduce, reuse, recycle, recover, redesign, and remanufacture) in order to establish a closed-loop material flow.

Sustainability in Manufacturing's sector is to promote the development of environmentally conscious businesses without losing profitability. Sustainable manufacturing was also termed by the American Society of Mechanical Engineers (ASME) (2014) as the practice of producing products that are both cost-effective and capable of satisfying the needs of a wide range of stakeholders, while also making efficient use of energy and raw material sources, leaving a light footprint on the environment, and encouraging the growth of environmentally friendly production methods, distribution networks, and supply chains. According to [5], the manufacturing sector's value is created via the collaboration of suppliers, manufacturers, customers, and other stakeholders. By gathering accurate data on inputs, processes, and outputs in real-time, digitalization enables manufacturers to enhance their operations in ways that are beneficial to both their bottom line and the environment.

Abdalla et al. [6], approach shows that many industries that utilize or supply this emerging technology are interested in more than just the financial rewards; they also want to address social and environmental issues while gaining a sustained competitive advantage to stand out in a market that is rapidly changing. Focusing on sustainable manufacturing across the whole supply chain and improving the company's own products, processes, and systems may provide a substantial competitive advantage [7]. Most strategies for establishing sustainable performance are deemed worthless without first optimizing production processes and systems. It is vital to improve the sustainability performance of processes and systems that simultaneously allow sustainable production. For this reason, it is essential to perform a thorough evaluation of how various levels promote sustainable activity.

Cost, standards, supply, adaptability, innovation, etc. are examples of competitive objectives that should be developed as part of the strategy, as mentioned by [8][9] . To promote economic viability in manufacturing,[10] proposed that a strategy should include not just the end product/service and the manufacturing processes utilized to manufacture it, but also the systems spanning from the production line to the plant level.

There is a scarcity of generally acknowledged performance measures upon which managers might base crucial decisions. Aside from a few studies and case studies, such as those found in [11][12][13][14][10][15], there has not been much research on the actual performance quality metrics used at the plant and line levels in a manufacturing facility. Managers used a variety of strategies to maximize revenues and accomplish business objectives.

The large field of measuring production via tests and other measures. And they are essential because the data they gather may be utilized for decision-making, tracking progress toward the organization's objectives, etc. across economic, social, and environmental aspects. According to [15], there are few user-friendly resources for measuring the commitment of manufacturers to sustainability. Various sustainability indicators have been developed and discussed [16][17][18][19][20][21][22], with a focus on the three pillars of sustainability [16][17][18] utilized the Dow Jones Sustainability Index (GRI) to describe how firms might approach performance from an economic standpoint, while [20] categorized evaluation methods and measuring indicators based on environmental issues.

Again, a manufacturing sustainability assessment tool should be built with the company's product-specific requirements in mind, and it should be adapted in a manageable and easily interpretable method and scope [23]. The categorized sustainability assessment instruments are grouped into three major categories: product-related assessments, indicator- or index-based methodologies, and combination assessment methods. Although [24] claimed that indicator- or index-based methodologies oversimplify the topic and are thus inadequate for a system-level review, many researchers continue to use them. Nevertheless,[20] discovered that, among the three primary kinds of sustainability assessment tools, indicator- or index-based methodologies are the most applicable due to their industry-wide applicability.

When developing metrics for evaluating sustainable manufacturing performance at the production line and plant levels, the manufacturing process is considered the basic unit to analyze. The many production process stages in a manufacturing system are arranged into workstations, which are then joined to create production lines.

It has been discussed whether or not different measurements are employed at various organizational or institutional levels. Existing research has concentrated on what plant managers believe is necessary to advance their company's profit targets, rather than on how measurements are collected and reviewed, who receives the data for measurements, or what purposes it serves.

Frameworks that contain the sustainability idea need to be thoroughly researched in order to enhance production line and plant performance assessment (concept-6). Literature study findings indicate that many studies provide little information on the structure required to improve analysis of production line and plant performance. The capacity of the system to implement the 6R principles is crucial for any thorough assessment of its sustainability performance. Product life cycle metrics that do not account for the period after purchase are often overlooked. Focusing on providing a full suite of sustainability data and an assessment approach to close this gap is the primary objective of this investigation.

Emissions, improper material waste and disposal procedures, and other elements of industrial activity increase environmental deterioration and so contribute to the mismanagement of our planet's key resources. It is perilous for businesses to disregard it at a time when they are under growing pressure to reduce their environmental impact. In the interest of its stakeholders, the manufacturing sector is under heightened scrutiny to enhance its competitiveness and decision-making ability. This study focuses on ways to secure the long-term economic boast of the manufacturing industry. This implies that the theoretical emphasis of this inquiry is primarily on plant and line-level production efficiency. This study aims to give a method for assessing the performance of manufacturing in a sustainable way by changing and enhancing an existing approach.

## II. METHODOLOGY

Several prior studies were produced with the purpose of gaining a greater understanding of the manufacturing industry's environmental impact effectiveness. To further demonstrate the recommended approach for determining the effectiveness of sustainability in manufacturing operations, indicators for Company X's (name withheld for confidentiality) production lines and facilities are chosen and analyzed.Numerous studies [25] [26] [27] [28] [15] [29] [14] [10] have used a number of case studies to illustrate the indices that will be considered while evaluating performance and operations. This study, however, chose for a larger emphasis and a more exhaustive collection of sustainability indicators arranged into sections that cover the three pillars of sustainability, the whole product life cycle, and the 6R principles simultaneously.

Numerous indicators and approaches have been used to evaluate the efficacy of a company's sustainability initiatives at the level of individual production lines and whole facilities [15]. The authors of this study conducted a comprehensive literature evaluation to determine the extent to which sustainable manufacturing techniques have been applied. The publications were selected from journals with peer review utilizing secondary sources such as Google Scholar and Science Direct. To achieve full utilization of the production line, which is a function of efficiency, quality, performance, and availability, better definitions of line and plant equipment and resource utilization based on linked activities of the concept of total equipment effectiveness are required (OEE). Using case studies and a study of the relevant literature, the performance of two firms that had embraced sustainable manufacturing techniques was evaluated.

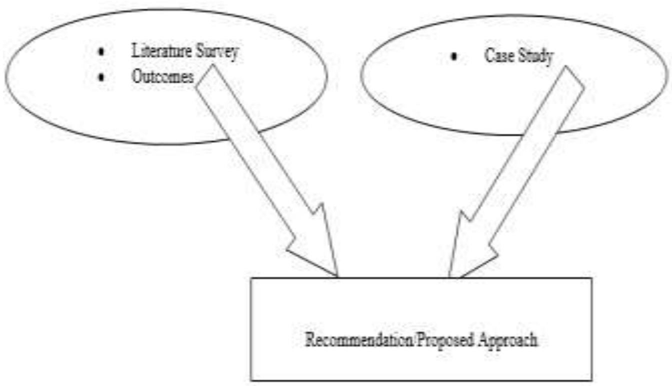


Fig.1: Proposed study design and research methodology

III. DISCUSSION

*3.1 Case Study 1 Analysis*

*3.1.1 Use Of Recycle-Friendly Automotive Aluminium Alloys*

According to a paper issued by Material Economics, as manufacturers convert to creating electric automobiles, demand for aluminum castings would decrease and post-consumer waste will increase. In the past several years, automakers' engagement in recycling activities has increased, although it was always there to some degree. A vehicle is continuously crushed by a car crusher to reduce its size for shipment to a mill. Each year, several automobiles reach the end of their useful lives, according to studies. If their metal and other components were recycled, these antique automobiles may still be valuable. One approach to see the outcomes of recycling is as a substitute for the original output [30]. The metals are extracted from shredded automobiles, and the remaining materials are machine-sorted for reuse in the recycling of other commodities, such as glass and plastics. The remaining material is referred to as "residue from automotive shredders" and is deposited in landfills.

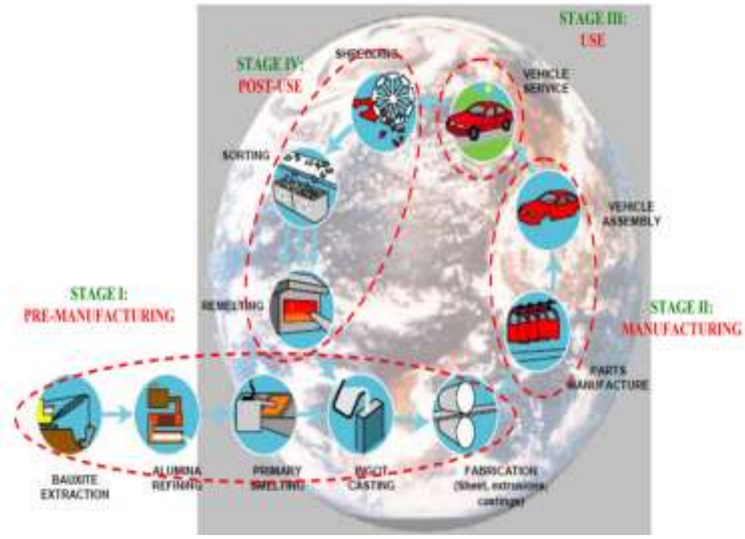


Fig.2: Life Cycle Management in the Aluminium Industry [31]

In order to get the proper consistency for various aggregates, aluminum scrap is frequently fused with more fundamental metals. The production of primary aluminum from bauxite is extremely energy-intensive. Therefore, it would save not just a substantial amount of material but also a substantial amount of energy if new vehicle components could be manufactured from worn ones without the usage of primary aluminum. As the need for aluminum castings decreases in the future, preventing the downcycling of wrought alloy waste in secondary aluminum for castings will become a key necessity in the attempt to increase the aluminum's circularity. Technically, it is feasible to recycle aluminum without degrading its quality [32], but cost, availability of processing facilities, and product criteria may limit the quality of recycled aluminum.

*3.1.2 Case 1 Performance at Production Line*

The organization has just implemented an instance-wide availability metric. However, the study did not account for the time necessary to install the system. From gathering components to packaging the final product, the complete procedure takes around 14 days. The 6R methodology of lean manufacturing enables closed-loop, lifecycle-based material flow at the production line, process, and plant levels.Shears and a standard shredder are used to chop the frames off first. After the primary separation, magnetic and eddy current separators are utilized to eliminate the remaining debris (such as metal hinges, plastic, and wood). The trash from the shredder is virtually entirely metal, but it also comprises aluminum scrap that was not part of the alloy used to manufacture the automobile component. Using advanced x-ray technology, we can avoid these undesirable effects. Our two-stage shredder first reduces the materials to very small bits, and then they are re-shredded and x-ray dipped to prepare them for our x-ray transmission equipment. The x-ray equipment demands greater accuracy than is offered by the typical shredder races. Aluminum may be cut into small bits using a specific blade made of steel. Due to the second screening unit's capacity to filter out the tinier particles, the material flow is more uniform. This enables X-ray devices to rapidly detect certain substances.

*3.2.3 Performance at the Plant Level for Case 1*

Due to the fact that traditional manufacturing processes only evaluate the design, production, and consumption stages of a product's life cycle, overproduction and unneeded disposal have been issues. Auto disassembly is the removal of a vehicle's components for the purposes of recycling or resale. Even after a vehicle's useful life has ended, it still retains value as a source of replacement components, thus giving rise to the auto dismantling business. Auto or automotive recycling facilities, wrecking yards, and dismantling yards are common names for the commercial locations where this takes place. In the automotive disassembly yard, there are heavy machinery and other complex production equipment. In a tiny area of the structure, research was done to determine whether or not a recycling workshop would be viable. Waste from automotive shredders frequently comprises non-collected recyclable items, such as polymers and residual metals. On a conveyor belt that leads to a specialized sorting machine that separates the shredded particles, improper alloys containing excessive amounts of other metals, such as copper or zinc, may still be found. Using two high-energy X-ray sources, or "sources," with a total of several electron volts, the pieces are analyzed independently. Aluminum chips are carried at a pace of 4 meters per second on a conveyor belt beneath X-ray lamps, while a detector beneath the belt detects any incoming radiation. Multiple layers of lead plate shield the machine from radioactive particles. By analyzing the quantity of radiation that is absorbed by scrap metal, computers are able to differentiate between the various aluminum alloys. The computer then commands a strip of air guns to blast away dust and other debris based on this information. With this technology, we can examine up to a thousand individual components with pinpoint precision. In the plant's cockpits, recyclables are melted down and, with the use of sophisticated machinery, aluminum ingots that are almost entirely generated from recycled aluminum are created. Aluminum may be recycled and reused several times during its entire life cycle, resulting in enormous energy and raw material savings. Recycling metals saves around 74% of the energy required to produce new metals. Therefore, car recyclers prevent the yearly waste of a substantial quantity of oil that might otherwise be used to produce alternative products.

*3.2 Case Study 2*

*3.2.1 Production of Carbonated Bottled Drinks*

Company X is a bottling facility that manufactures (FMCG). scheduled into three section, morning, afternoon, and night shifts. While at Company X's polyethylene terephthalate (PET) beverage production facilities producing and packaging approximately 80,000 cases of sellable key units per shift. From November 2021 to May 2022, all production runs at the facility were examined and data was collected.Due to the vast diversity of sizes and tastes of beverages generated by these lines, monitoring and evaluating production is essential. Along these lines, a clear framework for the production process' operations has emerged, which improves product quality, productivity, and efficiency while making better use of available resources. This framework is a strategic management strategy that reduces work-in-progress (WIP) and increases line operators' understanding of their tasks for increased production.In addition, production line operators are given a manufacturing system worksheet (SAP, SCADA, etc.) with clearly defined measurement parameters that monitor workflow, resource planning, and information sharing as production moves from one stage to the next, thereby facilitating a continuous flow of product and minimizing unplanned downtime.

*3.2.2 Processing steps*

This processing steps involve dividing them into a number of distinct categories and analyzing each one independently in order to make everything crystal obvious. There was a total of four (4) distinct workstations, comprising a section for the manufacturing of syrup, a section for molding, a section for filling and capping, and a section for labeling and packaging.Each of these stations is designed to receive the inputs or components required to bring the product's life cycle to a natural finish. The great majority of syrups are composed of a sugar-water solution containing around 85 percent sugar by weight. In addition, various chemicals, such as food coloring and flavoring, are commonly utilized in the manufacturing process. After water microbiological prefiltration and the injection of carbon dioxide ($CO_2$), the final and/or completed syrup is carried via process utility pipes to the filling station's storage tanks for usage in the production process. After forming the PET bottle, the pre-form material is transported to the blow molding machine in the shape of the created PET bottle. The blow mold machine then utilizes air to produce the blown bottle, which is subsequently cleaned and cooled in an extended mold bottle washer to eliminate any mold residue. After undergoing gas filtration at the filling machine, the final carbonated beverage is transferred to the equipment that seals the bottles.

Following the conclusion of the filling and capping procedures, the beverage is sent to the labeling station, where it receives production coding, batch marks, and labels in the specified sequence. The next phase will include utilizing a forklift to transport all of the products to the packing room, where they will be stretch-wrapped, palletized, and shrink-wrapped before being stacked on pallets, through the quarantine procedure, and then being sent to the storage facility.Among other things, an integrated PLC system interface, a P&ID module, and in-line process components such as valves and sensors are utilized to communicate the waste reduction and process control strategies used during the aforementioned processing phases.

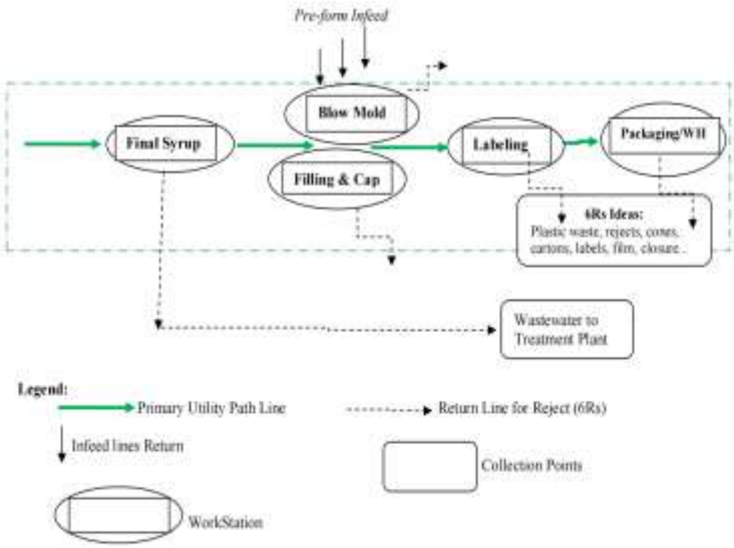


Fig.3: showing a visualized workstation model in the Plant

Figure 3 is a representation of a hypothetical model of the plant that depicts a typical configuration of the plant with multiple workstations constituting the production lines. The author's professional expertise and familiarity with the product's production methods guided the development of the parameters/metrics, while plant and line managers assisted in the analysis of those metrics.These information were readily accessible via the company manufacturing data records.

*3.4 Summary of Case Study Analysis*

*Case 1*

This study monitored the probable environmental influence categories and their severity over time using the LCI. In 2009, the International Energy Agency (IEA) estimated that aluminum manufacturing contributed 1% of worldwide yearly greenhouse gas emissions [33]. When a vehicle reaches the end of its useful life, some of its components can be recovered and used to lower the expense of recycling the vehicle in its whole. With more careful and purposeful end-of-life planning, environmental impacts, resource savings, and product longevity might all be improved. To reuse materials at the lowest possible cost, the recycling methods for automobiles are always changing. Auto recycling reintroduces nonferrous metals and aluminum into consumer markets, hence lowering the need for these commodities in new vehicles. Seventy-five percent of waste is collected for recycling, while the remaining twenty-five percent is sent to landfills. Used automobiles are a new source of aluminum for the recycling industry.Some of the components fed into other material cycles are unwanted heavy metal alloys; consequently, this technology attempts to both save the environment and stimulate the economy. These high-value scraps are easily loaded onto a truck and sent to a client, where they will serve as the primary raw material for pressing businesses to make aluminum ingots for the automobile industry. However, the production rate indication is applied more frequently. Due to the location and structure of the facility, determining the causes of downtime costs caused by process waiting time proved to be a daunting problem.

Since the alloy composition of the provided recycled materials matches the alloy composition required by pressing factories to produce vital vehicle components, this outstanding and novel sustainable technology helps us reduce our dependence on primary resources. Instead of being discarded, raw ingots are transformed into sheets, extrusions, and castings for use in the production of new vehicle components. Both matter and energy are preserved since the cycles conclude without new inputs of either substance or energy. This approach reduces carbon dioxide emissions throughout the production cycle, making it a feasible choice for the metals industry and environmentally concerned auto part manufacturers. According to [34], the processing of bauxite, the material from which aluminum is derived, generates significant GHG emissions and requires far more energy than the production of a range of other metals.

The challenges faced by factory personnel include simplifying production operations, adhering to environmental rules, and fulfilling the physiological and psychological needs of workers. The education, drill, security, and working environment initiatives intended to enhance employee and team development were all well-conceived. Numerous gains were discovered in these areas, which may be predecessors to future efficiencies and effectiveness of an even higher caliber. Business processes, traffic, and financial flows will all be managed by AI-based machines; medical diagnostics will be transformed; the decision-making process of insurance companies will change; decision documents will be made available to parliaments and governments; and AI-based machines will predict individual and group behavior by analyzing massive amounts of data [35].

*Case 2*

The effects of economic parameters, including process operational performance,direct and indirect production costs, were investigated. Once again, production is a function of manufacturing costs in an efficient system. A company can only create a profit under the added-value model if its production expenses are less than the value it generates. Whoever is responsible for determining if a product is suitable,manufacturer will typically consider the associated costs.

However, the focus of this study is on the performance of the process and operations, i.e., how effectively they optimize time, money, and other resources to provide a better outcome. Similar criteria including lead time, production, and personnel usage were also used to analyze operational efficiency in [14]. Manufacturing overhead, raw materials, and labor are the three basic components of direct expenses. [15], [22], and [27] all offer evaluation criteria for direct manufacturing costs.

A crucial statistic for measuring the social influence of a manufacturing process is the HSE (health, safety, and environment) of the industrial employees. Managers at every step of production should analyze the social influence of the product, and those in charge of the factory should do all possible to create a safe, happy, and healthy workplace for their employees. Taking into consideration the operator's best interests, various researchers including [14], [10], and [36] have accepted this criterion. This social indicator was meant to measure the well-being of line operators and the quality of their working environment. According to [37], noise levels in the workplace that exceed 80 decibels are hazardous for line workers. The following equation was developed by [37] to determine sound pressure:

Noise level

$$D = \frac{\text{actual time spent at noise level}}{\text{maximum permissible time at noise level}} \times 100\% \qquad (1)$$

Time-weighted average (TWA) of exposure during an 8-hour shift is determined as:

$$TWA = 16.61 \log_{10} \frac{D}{100} + 90 \qquad (2)$$

As demonstrated in the equations above, which represent the actual noise level measurement, line workers must wear personal protection equipment that helps to negate the noise level to which they are exposed.Previous study has examined the effects of the environment on product manufacturing in a number of different ways. A crucial aspect of sustainable manufacturing is the equitable distribution of inputs and outputs along the production chain.

Since avoiding negative environmental impacts is a primary issues that must be addressed [10]. Consumption of raw materials, energy (renewables -6Rs), and other resources provides insight into industry standards. In addition, the creation of pollutants and waste has a considerable negative impact on the environment, contributing to problems such as greenhouse effects, ozone depletion, ocean level rise, acidic waterways, etc. Supporting the 6Rs concept necessitates promoting a proper waste disposal system, waste reduction, and waste treatment, which will lead to product reuse through recycling and remanufacturing.

## IV. CONCLUSION

Based on a variety of case studies, this study analyzed and contrasted the different techniques used to measure sustainable performance in manufacturing at the plant and line levels, taking environmental, social, and financial issues into account. This study demonstrates that a disassembly and presorting technique that produces discrete alloy and/or component metal streams facilitates aluminum alloy recovery from recycled automobiles. Since a significant amount of carbon is emitted into the environment during the construction of new vehicles, some would claim that the "cash for clunkers" program did not assist many owners in reducing their carbon footprints. The notion of sustainable manufacturing gives the option for more productive material use by recirculating their large amount via reuse and recycling, so reducing waste in production and extending the lifetime of items, and by means of associated legislation. The use of ecologically friendly processes is the second phase in the manufacture of carbonated drinks. Throughout the beverage manufacturing process, energy-efficient techniques and cycle models may save energy and materials. This occurs as a result of the prevalent predisposition for wasteful resource use. Achieving sustainability necessitates reducing the inefficient use of limited natural resources, lowering the pace of environmental degradation caused by the exploitation of raw materials, and reducing the pollution created by these activities. The producers of carbonated bottled drinks put considerable effort to reduce consumers' water use. The concept of reusing wastewater has become more significant.

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