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Article

Supply chain best practices to improve bottle-to-bottle circularity of PET: Case evidence from the beverage industry

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Abstract: Bottle-to-bottle circularity of PET (polyethylene terephthalate) has gained significant attention in the beverage industry globally as a prospective response to unsustainable manufacturing and consumption. PET has been the polymer of choice for packaging of beverages for many decades owing to its functionality, resistance, safety, and lightweight properties. However, it has also created an environmental challenge as it has found its way to the landfill due to a lack of consumer awareness, robust collect-back mechanisms, and recycling options. Following the call of environmentalists, government legislations, and vigilante consumers, there is a conscious effort by the beverage manufacturers to move away from the traditional concept of "source-make-use-dispose" to design PET bottles with fewer resources, collect and recycle PET waste to avoid landfills. Bottle-to-bottle circularity of PET has two important processes: 1) design creation with minimal resource utilization in the forward logistics and 2) the 3Rs: recycle, reuse and recover in the reverse logistics. The academic literature on bottle-to-bottle circularity is nascent and focuses largely on the individual processes of the closed loop rather than considering them in conjunction or viewing them through the lens of supply chain management. This study adopts a supply chain management theoretical approach to understand the critical processes in the PET bottle-to-bottle circularity chain. A case study methodology has been adopted to analyze best practices adopted by three FMCG giants in recent years to improve their PET bottle design (without compromising on the material composition and quality), sorting and recycling mechanisms post-consumption, and finally incorporating the recycled PET in the new bottle design to close the loop. This study makes an important practical contribution, as the best practices highlighted in the paper can be adopted by other beverage manufacturers in the developing countries where sorting mechanisms and recycling options and technology are not well developed. It also fulfills the underlying principles of SDG (The 17 Sustainable Development Goals (SDGs), introduced by the United Nations in 2015, provide a comprehensive framework to balance economic growth, social inclusivity, and environmental preservation—fundamental principles of sustainability.) 9 and 12 that emphasize innovation and infrastructure development in industry to promote sustainable production and consumption.

Keywords: bottle-to-bottle circularity; PET (polyethylene terephthalate); design for recycling; post consumption collection and recycling mechanisms

1. Introduction and background

Single-use PET (polyethylene terephthalate) bottles, omnipresent in our daily lives, have been a popular packaging material in the beverage industry owing to their multiple characteristics, such as light weight, high strength, low cost, resistance to acid and alkali, and safety [1]. It is estimated that half a trillion PET bottles are produced worldwide each year [2] due to the growing demand for bottled beverages, particularly water, soft drinks, and juices. Only 9% of that production is recycled [3], and 22% is mismanaged. When PET is not effectively recycled, it negatively impacts the environment in numerous ways: polluting the marine environment as it is discarded in the ocean, bioaccumulation in the food chain, and persistence in the ecosystem, creating secondary pollution [4,5].

To counter these challenges, the concept of bottle-to-bottle circularity [6] has emerged in the last decade as a promising way to mitigate the environmental impact of plastic bottles and encourage a more sustainable approach to packaging. Bottle-to-bottle (B2B) circularity falls under the umbrella of circular economy with three fundamental principles, namely (1) innovative designs to reduce waste and pollution, (2) products and materials of the highest quality, and (3) regeneration of natural systems [7]. In addition, this circular system can be achieved by the 9 R framework: Refuse, Rethink, Reduce, Reuse, Repair, Refurbish, Remanufacture, Repurpose, Recycle, and Recover [8,9]. It also fulfills the underlying principles of SDG 9 and 12 that emphasize innovation and infrastructure development in industry to promote sustainable production and consumption. These goals are particularly relevant in transforming traditional linear supply chains into smart and sustainable ones, setting a benchmark for environmentally and socially responsible progress [10].

B2B circularity in particular has four essential stages: packaging design and material composition, post-consumption collection, sorting, and recycling of the used plastic bottles into new bottles [11], thereby closing the loop and maintaining the value of the material within the circular economy. Unlike traditional linear models of production and consumption that follow the source-make-use-dispose model, bottle-to-bottle circularity aims to create a closed-loop system where bottles are repeatedly recycled and reused, leading to minimized waste generation and resource depletion [12]. The benefits of bottle-to-bottle circularity are manifold. By recycling plastic bottles into new bottles, it conserves natural resources, reduces energy consumption, minimizes greenhouse gas emissions, and mitigates environmental pollution associated with plastic waste [13].

The concept of bottle-to-bottle circularity has two important loops: 1) design creation with minimal resource utilization in the forward logistics and 3Rs: recycle, reuse, and recover in the reverse logistics. At the onset of the creation of the bottle the design element needs to ensure that all components of the plastic bottles—bottle, label, and cap—are made of high-quality recycled materials that can be incorporated back into the production of new bottles. Many recycling technologies, ranging from mechanical recycling, chemical recycling, and biological recycling, have been developed to transform plastic bottles into recycled materials suitable for bottle-to-bottle applications. However, many limitations persist both in the forward loop relating to product design and material composition as well as in the reverse loop, relating to recycling infrastructure, options, consumer awareness, and behaviors.

Recent academic literature has focused on the reverse loop, i.e., the collect-back mechanisms, segregation, and recycling options, but has neglected the product design and development for a circular economy in the forward loop.

As the economic trends indicate that PET bottle waste generation is likely to continue increasing in the coming years, driven by population growth, urbanization, and consumption patterns. It is imperative that a conscious effort be made at the product design and development stage so that the recycling burden is reduced in the reverse loop. This paper has been developed with two main objectives in mind: 1) To highlight the beverage industry's supply chain best practices to promote bottle-to-bottle circularity 2) To provide recommendations/ways forward that other beverage manufacturers in the developing countries can emulate so that environmental impact of PET waste disposal to the landfill can be checked at a global scale.

2. Literature review

Academic discourse on circular and closed-loop supply chain management has been growing in recent years as researchers, policymakers, manufacturers, and industry professionals have shown keen interest in sustainable waste management and resource conservation of plastics. Circular supply chains are designed to enhance sustainability by minimizing waste and making the most of resources through recycling, reuse, and refurbishment. An integral part of circularity is designing products that can be fully reclaimed or reused at the end of their life (cradle-to-cradle model), contrasting with traditional "cradle-to-grave" models. To accomplish this, life cycle assessment (LCA) is required that evaluates the environmental impact of a product throughout its life cycle. The foundation of circularity and closed-loop coordination is systems thinking, which considers the broader system in which supply chains operate, emphasizing the interconnections between ecological, economic, and social factors. To operationalize the concept of circularity, various academics have proposed Material Flow Analysis (MFA), a method that quantifies the flow of materials within the supply chain, helping identify areas where circular practices can be implemented. Since the origin of products is conceptualized at the manufacturers' factories, Extended Producer Responsibility (EPR) holds manufacturers accountable for the entire lifecycle of their products, motivating them to design for longevity and recyclability. Encompassing the concept further nowadays, various options, such as product-as-a-service or take-back schemes, are being explored to promote resource efficiency and customer engagement.

Specifically, the literature on bottle-to-bottle circularity can be broadly classified into five themes: 1) Material science and engineering related to product design and development 2) Recycling strategies and processes that include life cycle assessments [14,15] 3) Policy and economics that play a large role in market dynamics influencing the adoption and scalability of bottle-to-bottle circularity 4) Reverse supply chain management to optimize collection, sorting, and processing of recycled plastics for bottle-to-bottle applications [14,16], and finally 5) Consumer behavior and perceptions influencing consumer choices, communication strategies, and interventions to encourage recycling participation (**Figure 1**). These five themes have been discussed through conceptual frameworks and models with case studies and best practices for implementing circular economy principles in the plastics industry.

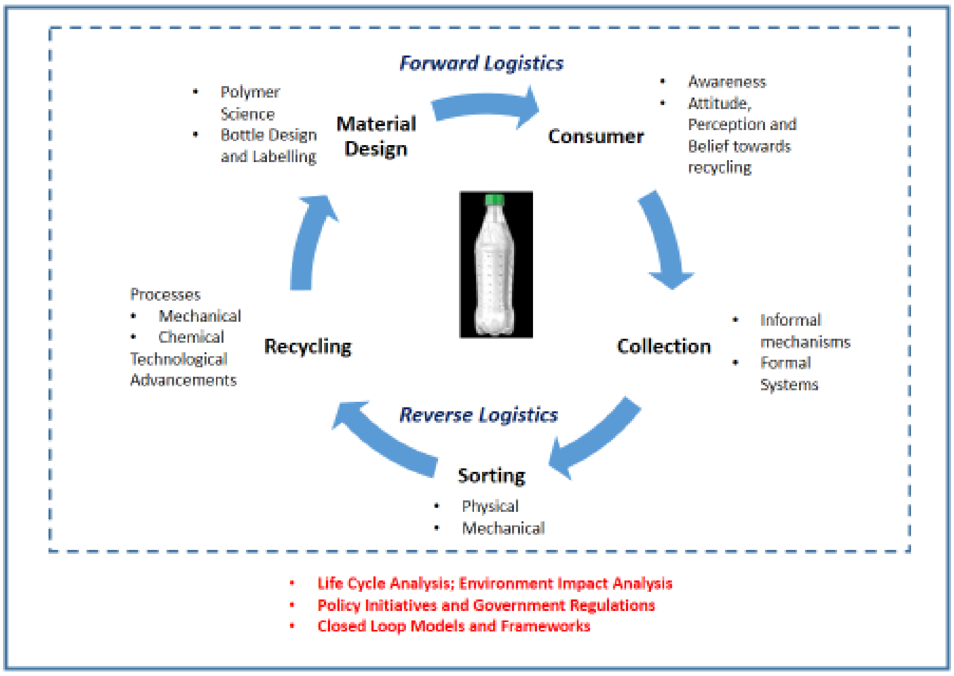

Figure 1. Different themes in the academic literature on one-to-bottle circularity of PET bottles.
Source: Author.

This review focuses on bottle-to-bottle circularity drivers, advantages and challenges, and supply chain processes, as it is the starting point of the circular supply chain of the PET bottles. In the beverage industry, there is growing awareness that PET packaging can be reused and repurposed, thus playing a crucial role in the circular economy. There is a conscious effort amongst manufacturers, consumers, and packagers, to work together and initiate substantial changes in the forward and reverse supply chain to achieve full circularity.

a) Bottle-to-bottle circularity drivers.

The two main drivers of bottle-to-bottle circularity are 1) legislation and 2) industry demand.

i) Legislation—Many global organizations such as the Ellen MacArthur Foundation, the World Economic Forum, the European Commission (EC), and the United Nations Environment Programme (UNEP) have called for advocacy and policy initiatives aimed at reducing plastic waste and promoting circular economy solutions for PET bottles and other plastics in the last decade. In 2015, a new legislative initiative—Circular Economy Action Plan, based on stricter rules and directives—was implemented by the European Commission (European Commission, 2019). The European Parliament and Council’s 2019 “Single-Use Plastics Directive” established new goals for the percentage of plastic bottles collected (77% by 2025; 90% by 2029) and the percentage of recycled content in PET bottles (25% by 2025; 30% by 2030). Furthermore, specific design specifications were outlined for PET bottles, including lowering the complexity of packaging materials and promoting packaging that is easily recyclable and reusable. The directions also included labeling that facilitates the correct separation of packaging waste.

Similarly, in the US, PET recycling rates range from 29%–37.8% (far above the global average), and demand for recycled PET (rPET) reached over 50% of end market consumption in 2022, as per the National Association for PET Container Resources (NAPCOR). The law in certain US states requires plastic beverage bottles to contain an average of 15% recycled plastic. This amount will be raised to 25% in 2025 and further to 50% by 2030 [10].

ii) Industry Demand—China has been leading not only PET production and consumption since 2010 [17,18], but also recycling PET bottles (about 71% in 2014) [5,16]. An estimated 30% of the country's total polyester fiber output comes from recycled PET bottles [19]. The reuse PET (RPET) industry has developed rapidly in China as more than 90% of post-consumer PET bottles are collected and recycled [20]. In 2020, 16 million tons of waste plastics were recycled in China, collected by the informal sectors through the downcycling process [21]. Bottle-to-bottle recycling is a more effective method of disposing of plastic waste than downcycling, allowing post-consumer PET to be recycled at high-level bottle grading. Some of the best practices adopted by advanced countries are listed in the table.

b) Bottle-to-bottle circularity benefits.

According to the LCA (life cycle analysis) performed by Ncube and Borodi [22], PET bottles have a huge environmental impact (summarized in **Table 1**) in terms of energy consumption and waste generation.

Table 1. Environmental profile for 1 kg of PET bottles.

	Energy requirement	**Emission**	**Greenhouse gases**
	(MJ)	**(g)**	**(kg CO_2-eq)**
PET production	83.80	2433.20	2.35
Waste recycled	27.10	170.25	0.98
Waste landfilled	60.00	2177.78	44.65
Waste incinerated	32.50	2019.65	1.95

source: Ncube and Borodin 2012 [22]

Bottle-to-bottle circularity offers several benefits: 1) Resource conservation: natural resources such as crude oil, used for making plastic bottles, can be conserved as the need for virgin materials reduces. 2) Energy savings: Less energy is consumed in the recycling processes as compared to producing new ones through extraction and refining of virgin materials. Moreover, greenhouse gas emissions are reduced, leading to less pollution. 3) Reduction of waste: As bottles are recycled, less plastic waste ends up in landfills or oceans, thus mitigating environmental pollution. 4) Economic opportunities: More economic opportunities are generated by establishing new industries and job roles in recycling, collection, and processing. 5) Brand image and consumer perception: Embracing bottle-to-bottle circularity enhances a company's brand image by demonstrating a commitment to sustainability and environmental responsibility. There is a growing awareness amongst consumers as they prefer products and brands that prioritize eco-friendly practices. 6) Regulatory compliance: Globally, many governments have implemented regulations and policies to promote recycling and circularity. Adopting bottle-to-bottle circularity can help companies comply with these regulations and avoid potential penalties or restrictions on their operations.

c) Bottle-to-bottle circularity processes.

Product design and development—PET offers many advantages as compared to other packaging materials such as glass and aluminum cans. It is lighter in weight when compared with glass. It is corrosion resistant compared to cans. It is very versatile in terms of design molding and can be offered in large pack sizes (up to 2 L). Also, the impact strength is greater than glass; it does not leave any splinters when broken. However, it is not without limitations—plastics do not offer complete protection against water vapors. This means carbonation can escape and oxygen ingress can occur over time. It is also susceptible to certain chemicals; for example, silicone sprays can induce stress cracking in PET bottle bases. The PET bottle design has 4 components: bottle color and material, cap and closure, and bottle label. The requirements of the manufacturer are to minimize complexity and reduce costs by reducing the use of virgin material. The formation of a PET bottle involves three steps: 1) conversion from monomer to resin, 2) resin to prefab bottles, and 3) fitting of closure and labels).

Used PET, from post-consumer waste, can now be incorporated into new bottles after processing with the use of new technologies. However, reprocessing reduces its strength, and no more than 20% recycled PET can be incorporated in a new bottle. The closures, made of rigid plastic (polypropylene or high-density polyethylene), come in two forms. First, a two-piece closure, which on compression forms a seal with the bottle finish. The second version can establish a seal with the bottle without a liner because it is composed of more flexible plastic, like high-density polyethylene. Wet glue is typically used to apply the wraparound labels that provide an economical way to convey the necessary legal and marketing information.

The consumption pattern of PET in the advanced countries is much higher as compared to the developing countries [23], hence, the collection systems and sorting systems vary. The life cycle of a PET bottle is depicted in **Figure 2**.

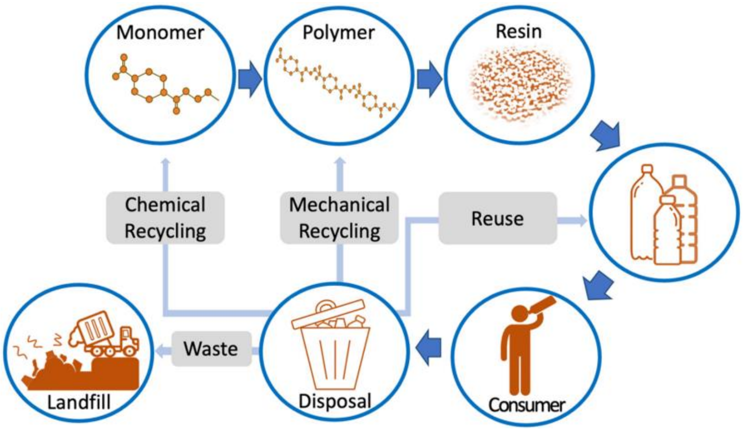

Figure 2. Life cycle of a PET bottle.

source: Benyathiar et al. (2022) [24]

Collection and sorting post consumption—Proper disposal of PET bottles by consumers post-usage and collection of plastic waste are very important steps to successful recycling. Many authors recommend segregation at the source to remove the recyclable plastic to prevent contamination and improve recovery for the recycling operations. Many models are followed in different countries for the collection of plastic bottles. These range from formal collection systems followed in the western countries to the informal collection done by the rag pickers in the developing countries. Firstly, the curbside collection programs [25,26] encourage complete waste segregation at the citizen end, where consumers separate the waste into different recyclable packaging material categories, such as paper, glass, metal, and plastic, at home. Each is then collected separately by the dedicated recovery facility. Secondly, sorting can be done at the truck level, where the driver is responsible for separating the materials into different categories. Thirdly, the segregation can be done at the MRF facility using either manual or mechanical methods. Finally, the co-collection method is followed, where collection does not distinguish between normal trash and recycled materials. For the first two models to be successful, consumer awareness and commitment to environmental protection are a must. In advanced countries, deposit systems are followed where monetary motivation is used to increase participation in recycling. These systems have an inbuilt deposit fee when the product is purchased from the retail store. The consumers receive their deposit back when they return the empty bottle to the collection center. In the developing countries, the last two options are more popular, as there is a lack of consumer awareness and well-established recycling systems.

Recycling—For many decades, bottle-to-bottle recycling of post-consumer PET packaging materials did not gain momentum because of underdeveloped technologies for decontamination of packaging polymers during first use or recollection. In recent years, the recycling systems for PET bottles have seen significant advancements as sophisticated decontamination processes and super-clean recycling processes have been introduced worldwide. These are able to decontaminate the recycled PET to concentration levels of virgin PET materials. As per Al. Salem et al [27], the PET value can be recovered with four main methods: primary (re-extrusion), secondary (mechanical), tertiary (chemical), and quaternary (energy recovery). Each method possesses unique advantages and disadvantages in terms of cost, quality, and environmental impact [27] To ensure complete decontamination of the recycled PET, super-clean recycling, also called deep-clean recycling, is used so that the end product is suitable for direct food and beverage contact packaging. Welle [28] recommends a three-stage super-clean process: (1) high-temperature wash, (2) gas wash, and (3) chemical wash to ensure contaminant-free recovery of the plastic [28].

Geyer 2020 distinguish between open-loop recycling (where a product is reused in a different application) and “downcycling” (where the quality of the recovered material is lower) and closed-loop recycling (where a percentage of PET recovered from the bottles goes back into the bottles) [29]. In an open-loop recycling system, the recovered PET (Rpet) can be utilized for items other than bottles since it differs from virgin PET in certain ways. However, Rpet may have low quality, as the raw material is gathered from multiple sources and the finished PCR PET pellet may contain a wide range of co-monomers and additives in different quantities. Additionally, the Rpets’ final hue may differ depending on the colors and contaminants present in the feed supply. The closed-loop system includes recycled PET merging with the virgin PET material in the manufacturing process, thereby minimizing the quality variations.

d) Bottle-to-bottle circularity challenges

Although PET bottle-to-bottle circularity provides numerous benefits, the processes involved for implementation are not without challenges. For instance, many developing countries lack the necessary infrastructure to collect and process PET effectively. Moreover, maintaining the quality of recycled PET (rPET) can be challenging due to contamination and degradation during recycling processes, which may further limit its use in high-quality applications. Also, current recycling technologies do not efficiently handle all types of post-consumer PET materials, especially those that are contaminated or mixed with other plastics. Finally, the regulations and environmental standards regarding the use of recycled materials also vary across regions. To navigate these challenges, businesses must adopt innovative strategies to improve the circularity of the PET value chain.

The findings from the literature review indicate that the concept of bottle-to-bottle circularity is an important subset of circular economy. However, at the supply chain level, the processes are still not well developed and vary across geographies and technologies. Moreover, the academic literature is divided into different streams based on individual supply chain processes (**Figure 1**). Each process has been discussed in isolation rather than analyzing it from an interrelated chain perspective. Thus, it can be inferred that the success of bottle-to-bottle circularity can only be achieved when all echelons of both forward and reverse supply chains work in synchronization, as there are many variables that impact the bottle-to-bottle circularity ecosystem.

3. Methodology

The academic research on circular economy has grown considerably in the last two decades and covers diverse themes and topics under its umbrella term. Since this concept involves the study of circular (open/closed) flow of materials and the use of raw materials and energy through multiple phases [30], no single study can do justice to the enormity of the topic. This research is conceptualized as an initial part of a large project that aims to trace and document the essential processes in the bottle-to-bottle circularity global value chain.

Many authors have recommended the use of the qualitative approach when flexibility in design and applications of knowledge is required. Through qualitative research, new insights into the phenomenon can be derived, although it may be subject to the researcher's bias. In qualitative research, the case study tool is considered to be most appropriate as it provides an accurate representation of the studied phenomenon [31].

Stuart et al. [32] argue that ''case studies should not be seen as a methodology appropriate only for understanding and the preliminary stages of theory development. Because of their observational richness, they also provide a means of refutation of, or extensions to, existing concepts''. The multiple cases selected in this study serve two purposes: 1) they provide an understanding of a phenomenon (bottle-to-bottle circularity) that is relatively new and is in the development stage; 2) there is an opportunity to extend existing theory on the circular economy concept when viewed through the lens of supply chain management. These are descriptive and exemplary and provide rich descriptions of a phenomenon [33]. A theoretical approach is adopted for the selection of the sample companies aligned to the previous research approach proposed by Eisenhardt and Graebner [34].

In case research methodology, data can be collected from multiple sources with the help of interviews, observation, documents, and artefacts analysis. For the purpose of this research, secondary data was collected from various internet resources such as company websites, news articles, and company annual reports. The three selected companies—Nestle, Coca-Cola and Danone—are world leaders in the beverage industry and are the largest consumers of PET bottles for their diverse product lines. **Table 2** presents salient characteristics of the selected companies.

Table 2. Salient characteristics of the selected companies.

	Nestle	Coca Cola	Danone
Yearly Turnover	CHF 93.0 billion	$46.074B	$29.144B
Product range	Food and beverage products	CSD and non CSD Beverages	Dairy ad plant based Waters Specialized nutrition
PET Bottle-to-Bottle Circularity Goal	95% of plastic packaging to be recycled by 2025	50% recycled material in fresh bottles by 2030 100% packaging recycled by 2025	100% of packaging to be reused, recycled, or composted by 2025
Usage of PET bottles	1.2 million metric tons in 2024	26 million metric tons in 2024	10 million metric tons in 2024
% recycling of PET bottles	7.7% recycled plastic content	45% recycled plastic	77% of plastic packaging is recycled and reused

Source: Compiled from companies' websites.

4. Result

4.1. Case 1—Nestle

Nestle is a global transnational beverage brand manufacturing and selling diverse range of products such as milk based beverages. Nestlé's efforts to develop sustainable packaging across its product portfolio have been ongoing for almost a decade. Nestlé used slightly less than 0.9 million metric tons of plastic packaging in 2022, a 35% weight drop from 2019. The company aims to design more than 95% of its plastic packaging for recycling by 2025, a 12% increase from 2023. The company is conscious of developing all four stages of bottle-to-bottle circularity: To encourage consumers to recycle easily, Nestle. It is estimated that 4500 metric tons of PET plastic will be sorted accurately at the recycling facilities.

Nestlé has recently introduced a new recyclable shrink sleeve label in the US for its seven ready-to-drink Nesquik flavored milk products, where the cap, bottle, and sleeve can be recycled together as a single unit. This was necessary as the shrink sleeves were a common barrier to proper bottle recycling, as they used certain materials, inks, and adhesives. It has invested almost five years to develop the new sleeve technology that will be subsequently introduced to the other beverage lines, such as Coffee-mate, natural bliss, and Nestlé Sensation lines. The R&D included completion of plastics recyclability tests, such as checking for proper sorting at MRFs and ink washability.to ensure the new shrink sleeve and inks would remain compatible with the U.S. recycling system. The recyclable shrink sleeve design also features light-blocking technology to preserve taste, color, and vitamin levels. Also, by 2025, the company will reduce virgin plastics use by one-third from a 2018 baseline.

In 2020, the company removed plastic straws by developing paper-based alternatives and 'straw-less' designs. It also removed the plastic tear-offs that cover the bottle cap and neck from *Nestlé Pure Life* water bottles in Egypt. This resulted in removing close to 240 metric tons of PVC. In the US, the company eliminated the over-cap lids from all our *Gerber* 1st Food and 2nd Food puree tubs, removing over 2300 metric tons of plastics. Nestle abides by the rule that applies to all packaging: optimize the environmental performance of the packed product and use the maximum possible recycled materials.

Currently, recycled plastic content use is 7.7% globally. Additionally, the company uses more than 12% recycled content in the PET water bottles. The company sources food-grade recycled plastics and encourages increased recycling rates in order to reduce the usage of virgin plastics. The business has set aside about CHF 1.5 billion to encourage the market to source post-consumer recycled plastics and is willing to pay a premium price for these materials.

4.2. Case 2—Coca-Cola

Coca-Cola Consolidated, the beverage corporation's biggest bottler in the United States, is collaborating with R3cycle, a plastic processing company, to introduce bottle-to-bottle recycling throughout its 14-state areas as part of this initiative. By 2030, Coca-Cola's objective is to use 50% recycled materials in all its manufacturing units. By the same year, it also hopes to "collect and recycle a bottle or can" in exchange for every unit sold.

Worldwide, Coca-Cola aims to make all of its packaging recyclable by 2025, as compared to 90% in 2022. Recently Coca-Cola has introduced Sprite and Sprite Zero "on-the-go bottles" without labels. Traditional wrap labels have been replaced by a laser-engraved product and nutritional information on the rear and an embossed logo on the front. Clear plastic will also replace the green plastic bottles used for other brands, such as Fresca, Mello Yello, and Seagram's ginger ale.

As per the company's sources, although beverages' wrap labels don't hinder recyclability, removing them reduces their separation during the recycling process. Eliminating labels also decreases the amount of packaging material associated with each bottle, as it works to slash 3 million metric tons of virgin plastic from non-renewable sources by 2025, from a 2020 baseline.

The company announced in 2022 it would change its green Sprite bottles to clear PET in North America in a bid to increase their bottle-to-bottle circularity. The bottles, with the exception of their caps, are made entirely from recycled PE. The company has also invested in attaching caps to bottles to decrease littering, along with lightweighting bottles to reduce material.

According to the company's 2022 sustainability report, a variety of Coca-Cola brands in China, South Korea, and Japan provide label-less bottles with laser engraving to increase recyclability and reduce carbon emissions. Coca-Cola collected 61% of the equivalent bottles and cans that were put into circulation in 2022, using

15% rPET in their bottles. Green and other colored plastics were recycled into single-use products like carpeting and clothes that could not be recycled into new PET bottles, with the goal of increasing the amount of recycled plastic that could be used for food packaging.

"Taking colors out of bottles improves the quality of the recycled material," The new clear Sprite bottle will also feature a revamped logo, packaging design, and "Recycle Me" messaging.

The company has invested in developing systems such as collection tracking to account for material collected. The company and bottler teams are financing system-led collection initiatives in markets with limited recycling infrastructures (including parts of Latin America, Africa, and Asia) to supplement national systems. They have launched their own tracking systems. In 2023, they incorporated system-led collection data into their aggregate numbers. Most Dasani water bottles in North America are now made entirely of recycled PET (rPET), according to the firm. In 2023, this initiative reduced greenhouse gas emissions by more than 25,000 metric tons and saved more than 20 million pounds of virgin plastic compared to 2019. The business is collaborating with communities and partners to boost recycling among people in order to address the rPET supply issue.

4.3. Case 3—Danone

Danone is a world leader in four businesses: Essential Dairy and Plant-Based Products, Early Life Nutrition, Medical Nutrition, and Waters. The goal of the company is to offer nutritious, high-quality food and drinks in packaging that is 100% circular and utilizes low carbon. Danone's journey towards a circular economy of packaging started in 2017 when the company signed the Global Commitment on Plastics, led by the Ellen MacArthur Foundation in collaboration with the UN Environment Program. Since 2018 the company has made noticeable progress in fronting the packaging transformation. 84% of the packaging used by Danone in 2021 was reusable, recyclable, or compostable (compared to 80% in 2018). Between 2018 and 2021, Danone reduced its plastic use by 60,000 tonnes overall and nearly 90,000 tons for virgin plastic, a 12% virgin plastic reduction over this period.

> *"A circular economy approach to packaging requires a new way of working across the entire system. It means we must build and leverage strategic partnerships with a whole range of actors-start-ups, NGOs, research institutions, public authorities (international, regional, national or local) and other private companies. This includes taking a pre-competitive approach, meaning that - subject always to applicable competition laws-we work with our competitors to develop new, commercially viable technologies"—Danone Packaging Policy (Danone website)*

To ensure that packaging is both functional and compatible with circular economy principles, Danone initiated a design change in 2018. Over 50% of Danone's water volumes are sold in reusable packaging (e.g., AQUA, Bonafont, Hayat, Sirma, Villa del Sur). For its Evian range, it has eliminated non-recyclable shrink film and developed a new way of multipacking PET bottles using specially designed adhesive and tape handles. Danone has been actively supporting new recycling technologies such as capturing and converting CO_2 to make plastic bottles. In 2022, the company secured partnerships with Loop Industries to enhance closed-loop recycling for PET bottles and enable the recycling of hard-to-recycle packaging and materials. In the same year, the company joined the Business Coalition for a Global Plastics Treaty that endorses a common vision to end plastic pollution. In 2023, Danone removed PET labels from its Actimel yogurt drink concentrated shots and replaced them with embossed information to reduce its plastic usage by 135 metric tons of plastic annually.

However, the company has also faced challenges such as underdeveloped collection and recycling infrastructure for yogurt cups, underdeveloped reuse infrastructure, and scarcity of recycled content.

5. Discussion

The beverage industry has been a driving force in promoting supply chain innovation to enhance PET bottle-to-bottle circularity. The case companies presented in this study have set ambitious sustainability goals and have made significant progress in managing all aspects of PET bottle-to-bottle circularity, starting from product design development, sorting and recollection of bottles post-consumption, and then incorporating the recycled PET back into the new bottle development. These companies have set an example with their efficient recycling systems and technological innovations, and by implementing best practices and collaborating with supply chain stakeholders, they have contributed immensely to a more sustainable future. A cross-case analysis (**Table 3**) reveals several thematic patterns, such as configuration and limitations of forward and reverse supply chains in the B2B circularity. It also identifies region-specific challenges that can be addressed through transferable strategies across different countries.

Table 3. Cross case analysis (all data used in the table is from companies' website and annual reports).

Supply Chain Best Practices	Nestle	Coca Cola	Danone
End- to End supply chain management Material Design and Development	Reduce the use of virgin plastics in packaging by one-third by 2025 unnecessary plastic lids, accessories, layers, and films increasing the quantity of food-grade recycled plastic beyond rPET	Green Sprite to Clear PET Eliminating labels from the PET bottles Attaching caps to bottles to decrease littering, along with lightweighting bottles to reduce material	reduced its plastic use by 60,000 tons overall and nearly 90,000 tons removed PET labels from its Actimel yogurt drink concentrated shots or virgin plastic multipacking PET bottles using specially designed adhesive and tape handles to eliminate non-recyclable shrink films
Collection and sorting post consumption	supporting the development of well-functioning collection and sorting schemes	collected 61% of the equivalent bottles and cans for recycling	Co-building effective, efficient, and inclusive collection and recycling systems Deposit Return Schemes (DRS)
Recycling	Dedicated recycling facilities	collection tracking guidance system to account for material Company and bottler teams in markets with limited recycling infrastructures have financed system-led collection initiatives to supplement national systems	Loop Industries to enhance closed-loop recycling for PET bottles and enable the recycling of hard-to-recycle packaging and materials.

Table 3. (*Continued*).

Supply Chain Best Practices	Nestle	Coca Cola	Danone
RPET into new bottle design	20%	15% rPET in its bottles Dasani water bottles in North America to 100% recycled PET (rPET)	84% of the packaging used by Danone in 2021 is reusable, recyclable, or compostable Usage of recycled content in new bottles was 11% in 2021—Rebotella bottle—the first in Argentina to be 100% recyclable and made with 50% recycled plastic
Investment	CHF 2 billion to lead the shift from virgin plastics to food-grade recycled plastics	$137 million in recycling tech investments	Business Coalition for a Global Plastics Treaty

Forward supply chain—The cross-case analysis reveals that it requires an end-to-end supply chain approach involving multiple stakeholders, namely beverage manufacturers, material reclaimers, PET recyclers, converters, and responsible consumers, to implement bottle-to-bottle circularity successfully. An isolated initiative at a single node does not yield effective results. However, maximum responsibility rests with the beverage manufacturers, as they have the necessary resources and the power in the supply chain to drive changes.

The beverage manufacturers worldwide are focusing on product design and development, as this stage is crucial to reduce the recycling burden in the downstream chain. All three companies have made substantial investments to implement design changes, such as reducing the use of virgin plastic, shifting from colored bottles to clear plastics, attaching caps to the bottles, and eliminating the labels from the bottles. As the demand for virgin plastic can be reduced by increasing the use of recycled content in the plastic bottles, all three companies had increased the usage of recycled plastics (rPET) in their new bottles. However, this cannot be implemented globally, as many countries do not allow the incorporation of rPET in the new bottles due to the fear of contamination. It is noteworthy that new technologies have been developed that can easily remove the food contaminations from the recycled plastics, and this makes it safe to be used in the new bottles. Moreover, only a certain percentage of recycled plastic can be incorporated into the new bottle to avoid compromising on bottle strength and quality.

A small design change, such as bottles with fewer layers, using bio-based plastics, or exploring compostable packaging options, can yield large positive results. These beverage companies, such as Coca-Cola and Danone, have invested in material science research to develop clear bottles that are easier to recycle or use alternative materials that are more eco-friendly. Practitioners should adopt a label-free design that can satisfy both environmental considerations and customer value. It would be a formidable challenge to change the longstanding emphasis placed on label design, but this study demonstrates the value of doing so. [35]

The economics of bottle-to-bottle circularity depend on factors such as the availability and cost of recycled materials, the price of virgin materials, and market demand for recycled products. Fluctuations in these factors can impact the viability and competitiveness of bottle-to-bottle recycling compared to traditional manufacturing processes.

Reverse supply chain—The cross-case analysis also reveals the challenges faced by the organizations on their journey towards bottle-to-bottle recycling of the post-consumer PET packaging materials. These findings are in line with research done by Welle [36] that states that reverse logistics of PET is not well developed due to a lack of knowledge about contamination of packaging polymers after first use or during collection and a lack of robust recycling processes, especially in the developing countries. Contamination of the bottles post-consumer disposal can occur due to various factors such as mixed materials, food residues, or non-recyclable items being included in the recycling stream. This reduces the quality and usability of recycled materials that can be incorporated into the new bottles. Thus, the recycled plastic may have lower quality and performance characteristics as compared to the virgin materials. This can pose serious challenges in compliance with regulatory standards and consumer expectations, especially for high-quality plastics, such as food-grade packaging. To avoid this challenge, the case companies have been leading the reverse logistics channel with dedicated consumer education programs regarding the benefits of recycling and also rewarding the consumers with deposit schemes. Deposit return schemes incentivize consumers to return their used bottles at the designated collection points in exchange for a refund. The sorting is done either at the collection center or the recycling center. Two advantages of the deposit return scheme are 1) assured supply as collection rates increase and 2) improved quality of recycled materials.

Lack of consumer awareness and participation in recycling programs, as well as confusion about which plastics are recyclable, can contribute to lower recycling rates and increased contamination. Addressing these challenges requires effective education and outreach initiatives to encourage proper recycling practices among consumers. In this context, consumer awareness, behavior and attitude towards recycling PET bottles need to be studied extensively to understand the effectiveness of these programs.

It is quite evident from the research that effective bottle-to-bottle recycling relies on efficient collection and sorting infrastructure to separate different types of plastic bottles and remove contaminants. Inadequate infrastructure (whether government-led or through the industry participants), particularly in regions with limited recycling programs or low consumer participation rates, can be a severe limiting factor to the scalability and effectiveness of bottle-to-bottle circularity. It was also found that all three case companies had close collaboration with the recyclers, especially Danone, for improved collection, sorting, and processing of used bottles. A close collaboration with recyclers also help in maximizing the amount of material that can be reused in new bottles.

Policy implications—Finally, all three case representatives operate forward and reverse supply chains of PET bottles in more than 100 countries ranging from advanced, emerging, and underdeveloped economies, and they encounter different rules and regulations related to plastic waste and recycling in these countries. Inconsistent or inadequate policy and regulatory frameworks related to recycling and circular economy initiatives can impede the development and implementation of bottle-to-bottle circularity. In advanced countries, the regulatory frameworks and policies are in place, and hence, the biggest motivation for these case companies implementing bottle-to-bottle circularity is proactive compliance with regulations related to plastic waste and recycling. These companies have made substantial efforts to initiate bottle-to-bottle recycling programs in emerging countries where the consumption and volume of PET waste generated are very high (**Table 4**). Hence, clear and supportive policies are necessary to incentivize investment in recycling infrastructure and promote the adoption of sustainable practices across the supply chain.

Table 4. Best practices from different countries.

Germany	Japan	United States	China
Deposit systems incentivize consumers to return the bottles for recycling, leading to high collection rates	Advanced recycling technologies that can produce high-quality recycled PET material	Expansion of Recycling Infrastructure	Deposit-Refund System (DRS) to encourage consumers to return bottles in exchange for a refund
utilizes advanced sorting technology to separate PET bottles from other types of plastic waste	Extensive consumer education programs to raise awareness about the importance of recycling PET bottles	Collaboration between recycling companies and beverage companies	banned the import of contaminated recyclable materials, including PET plastics
collaboration between government agencies, recycling companies, and manufacturers	Collaboration with Manufacturers: for a steady supply of recycled PET material	Investment in Research and Development	Establishment of a Resources Recycling Group to streamline recycling across sectors, including plastics

Source: Compiled by author.

These case companies have increasingly prioritized supply chain transparency to trace the origin of their bottles and ensure ethical and sustainable sourcing practices. An integral part of managing supply chain transparency is working with suppliers who prioritize environmental stewardship and social responsibility. In this way, they can contribute to the broader efforts to promote bottle-to-bottle circularity. **Figure 3** presents the roadmap that actors in the forward and reverse supply chains can follow to encourage bottle-to-bottle circularity in the bevarage industy.

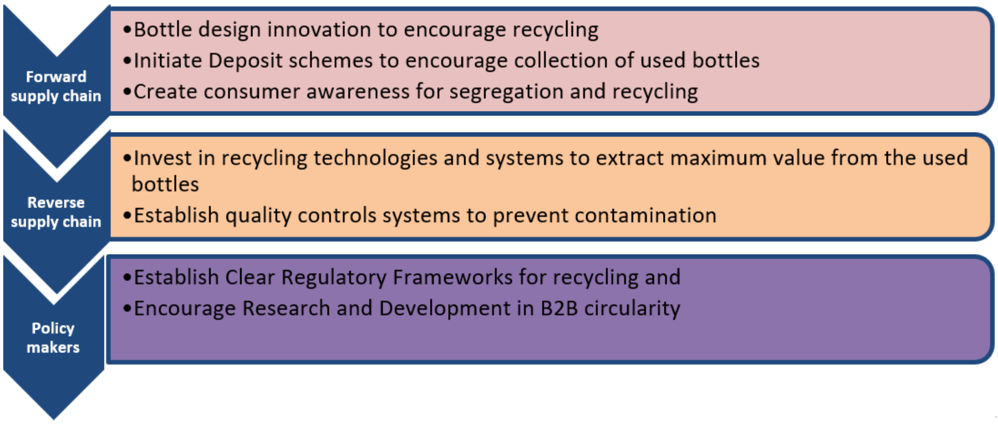

Figure 3. Roadmap for implementing bottle-to-bottle circularity in the beverage industry.

6. Conclusion

This research on bottle-to-bottle circularity offers a promising pathway towards a more sustainable and circular approach to plastic bottle packaging used in the beverage industry in alignment with the UN Sustainable Development Goals. By closing the loop on plastic bottle waste through material design innovation and promoting the reuse and recycling of materials, bottle-to-bottle circularity represents a transformative solution to the environmental challenges posed by plastic bottles, paving the way for a more sustainable future.

The case companies selected in the study are world leaders in the beverage category and possess the necessary resources and power in the supply chain to initiate and lead the change. They have demonstrated that design enhancements of bottles for recycling (design for recycling) are the key to reducing the burden on the downstream chain, i.e., collection, sortation, and recycling. Future investment in new recycling technologies and commercial adoption needs to be supplemented by recycling legislation permitting the use of rPET in food and beverage packaging, especially in the emerging markets and underdeveloped countries. Newer ways must be developed to empower the informal waste collection sector in the circular economy.

However, the continuous circulation and material flow in the loop are only possible when there is 100% awareness and participation of the consumers for PET recycling. As this research has not focused on consumer behavior and attitude towards PET recycling, the limitation can be overcome by future research projects. As the case companies demonstrate that bottle-to-bottle circularity is a global phenomenon and cannot be achieved completely without equal participation of the western and eastern countries. Hence, additional research is required to understand the cultural and infrastructural differences of the western and eastern countries.

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