Circular Supply Chain Management

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Abstract  Modern supply chain management has been shifting away from the traditional linear supply chain model of “take-make-use-dispose” as it is not environmentally sustainable. The circular economy principle brings forth circular supply chain to cope with the ecological threats caused by the linear supply chain by addressing material circularity. The fundamental concept is to prolong material utilization and reduce material exploitation, while capturing and recreating new values of the products and services along the supply chain. This chapter describes the basic principles of circular supply chain, as well as different circular supply chain models. Various circular value creation guidelines are presented to encourage new circular businesses. Bio-base materials which follow a different cycle from the traditional industrial ones are examined. Different performance measures of circular supply chain to assess how well different parties in the circular supply chain have accomplished are introduced. Implementation strategies and various technologies for the future circular supply chain are also discussed.

Keywords  Circular value creation · Circular supply chain models · Circular economy building blocks, Measures, and strategies · Digital technologies · Bio-based materials and energy circle · Product-as-a-service model · R principles

Learning Objectives

• Distinguish between traditional linear supply chain and circular supply chain.
• Be able to apply R principles in the context of circular supply chain.
• Understand different circular supply chain models, circular value creation, and energy cycle of bio-base materials.
• Identify building blocks, measures, and implementation strategies in circular supply chain.
• Design business model to achieve circularity.

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1 Introduction

Supply chain management has traditionally been concerning how to efficiently and effectively deliver goods from the sources to the consumers. Economic returns are the main focus of this linear economic model where the resources are extracted or acquired to make products and then disposed of after their potential lives. This model often ignores societal implications and conservation of scarce resources. It is only recently that managing of the supply chain has been gradually moving away from the “take-make-use-dispose” practice and starts to include “reverse logistics” to collect end-of-life products, recreate values of the returned products in “closed-loop” supply chain, and now recouple economic values of the returned materials as inputs in “circular economy”.

Figure 1 illustrates traditional linear supply chain where virgin material is acquired and transported to the raw material producer. This raw material is then sent to the product manufacturer to produce the finished goods, which is sold to the consumer. After the end of the product useful life, the product is discarded as waste. The circular supply chain begins similarly as in the linear supply chain. However, in the circular supply chain, the used products can be reused by the consumer or go directly to a resell market (such as garage sell or an online platform like Craigslist). Some of them are collected and sorted by a collector. Certain used products could be refurbished or remanufactured, and so they can be used by the product manufacturer. Some returned products need to be recycled or recovered by being physically transformed into raw-material-like substances prior to being reused later on in the circular supply chain.

Fig. 1 Linear supply chain and circular supply chain (Credit: Illustration by Sawaros Thongkaew from STEAM Platform)
Circularity of material is the key feature in circular economy and the need for a new supply chain model is prominent. Materials such as gold, silver, zinc, indium, iridium, hafnium, and terbium which are vital to many industries could be depleted in the next fifty years if we remain business as usual. Commodity prices have been drastically increasing since the turn of this century, erasing all the price decline due to production and logistics efficiency of the entire previous century. An estimate of three billion additional middle-class consumers are entering the market by 2030, while the total world population is going to exceed nine billion by 2050. This growth of the global population accelerates increasing demands; at the same time, catalyzes the needs for radical changes in material efficiency, minimization of energy, as well as reduction of waste along the supply chain. Without any change, there may not be enough futile lands, materials, and other resources for future generations.

Despite various arguments on how the circular economy (CE) is rooted, it offers a new economic concept that is both restorative and regenerative by intension and design. CE encompasses environmental economics, industrial ecology, ecological economics, and “cradle-to-cradle”. To realize the potentials of CE, changes in economic and social activities in all micro-level (individuals and within a firm), meso-level (network of firms), and macro-level (policies and regulations) are required. The following principles are examples of how changes may be formulated.

2 R Principles

In every supply chain, there are flows of materials, information, and fund. The three flows are intertwined through space and time. For example, an order triggers production and causes a request to transport the product to the customer, while there are financial transactions throughout the supply chain between the parties involved in the chain. Operation activities are usually monitored and data are collected and analyzed to improve the efficiency, transparency, and connectivity along the supply chain. By-products and wastes are treated, recycled, or disposed of.

In addition, CE includes simple yet effective actions for us as individual consumers and firms to lessen the burden for material input requirements. Those actions are Reduce, Reuse, Remanufacture, Recycle, and Recover.

- **Reduce**: Reduction of material or resource requirements lessens the need for virgin material acquisition. To reduce the need for resources, it often entails rethinking or redesigning of the product or process. Examples of new designs can now be seen in everyday life such as juice and water containers, as well as food packages that use less materials but maintain or sometimes exceed their primary functions. New production processes are equipped with modern technologies in conjunction with information collection function to adjust parameters suitable for the inputs or production plan to not only reduce the amount of material inputs, but also save energy and cost.
• **Reuse**: Certain products can be used several times without losing their main functions. Coffee shops that discount the drinks to customers who bring their own reusable tumblers are commonly seen nowadays. To encourage shoppers to reuse shopping bags, supermarkets in several countries charge bag fees if customers request new plastic or paper bags from the stores.

• **Remanufacture**: When a product malfunctions, repairing, refurbishing or remanufacturing can prolong the useful life of the product. Replacing certain parts while retaining other well-functioning parts reduces the need for new materials and saves cost. It is projected that new generations of mobile phones will be redesigned so that new models can be remanufactured using parts from the discarded ones. Customers who turn-in their used mobile phones may be benefited by obtaining a discount to purchase a new phone.

• **Recycle**: If the products cannot be reused or remanufactured, another option is to try to recycle their materials. Recycling requires transforming physical phases of materials through energy with proper handling and processes. Metals, plastics, and papers are common materials that are recycled. Certain recycled materials that if they are used to produce the original products can exhibit inferior properties in comparison to virgin materials. These materials could be used for different but yet valuable products. An example is a fabric made from recycled plastic bottles. The fabric is now used to make raincoats and reusable shopping bags.

• **Recover**: Recovery is employed when waste is converted into resources such as heat, electricity, or even fuel. Once considered as wastes, biomasses from farming, particularly in agriculture-base countries, are converted into sources of energy to be used in postharvest processing. Plastic waste is known to be able to be turned into fuel although its economic viability remains questionable.

Reduce, Reuse, Remanufacture, Recycle, and Recover (5R) principles should be applied by all the parties throughout the supply chain including the customers themselves. From the perspective of reducing the need for virgin materials, reduce in the 5R principles tends to be more effective as it directly decreases the demands and material needs. To reuse the product, the customer may need to wash or clean it which may induce environmental impact from the cleaning process with a cleaning agent. For remanufacture, recycle, and recover, the impacts to the environment increases, respectively, when the principles are practiced. Thus, it is advised to start from reduce and then extend to other principles as shown in Fig. 2. Disposal is used only after all the above options are exploited. Common disposal methods are landfilling and incineration.

3 Circular Supply Chain Models

For a long-lasting business, its operations must create economic value or the equivalence of financial return. Circular economy is relatively a new economic concept. For the concept to work, it requires an innovative value creation with radical
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or incremental changes to deliver that value—through goods or services—to the customer.

For example, Google data centers have adopted the circular economy concept and are able to claim hundreds of millions of dollars per year in cost saving and new revenue earning. Circular economy practices at Google can be grouped into three dispositions: inventory management, re-sale/remarketing, and material recycling (see Google Data Centers example for details). Another example is a French car maker, Renault, who is also an early adopter of the circular economy model. Renault makes changes in several of its operations, including remanufacturing of used components, managing material flows, manufacturing service improvement, and new business model of electrical-vehicle battery ownership. These changes generate nearly $270 million dollars annually and saving of 20–88% in various operations along the company’s supply chain (more details are in Renault example).

**Google Data Centers [6]**

Once servers at any Google’s data centers are decommissioned, they are dismantled. Usable components such as CPUs, motherboards, hard disks, and memory modules that pass the quality inspection are kept as refurbished inventory. These refurbished parts are then used to build remanufactured servers and are deployed back into the centers. The centers thus utilize both the latest technology platforms, as well as older ones. Both new components and refurbished ones are equivalent once they are in the inventory.

Maintenance and repair are also practiced regularly to prolong the life expectancy of the servers. Google internally assesses component inventory every quarter. Any excess is sold to secondary markets through selected remarketing partners. In 2015...
alone, Google resold almost 2 million units. Components such as hard drives and storage tapes that cannot be resold are crushed and shredded. They are securely processed as electronic waste and sent to recycling partners. Recycled materials can later be turned into reusable materials. The saving from these dispositions of circular economy throughout the supply chain of the data centers ranges from 19 to 75% of Google’s normal operations.

**Renault** [2]

Since the adaptation of circular economy, Renault has been realizing economic benefits in several of its operations. The followings are examples of circular economy practices at the company.

**Part Remanufacturing:** The company invested in redesigning its automotive components to increase the reuse ratio and standardize components for easy sorting. Although the labor cost has increased, the saving is realized in less machining of parts, higher material yield as there is less waste, as well as energy and water usage reduction.

**Raw Material Stream Management:** End-of-life vehicles are dismantled and quality materials are recycled. Design adjustments of several parts enable materials from used vehicles to be turned into high-grade materials for new cars. Renault also works closely with the steel recycler to provide steady streams of raw materials.

**Internal Service Improvement:** Across Renault’s supply chain, the company actively seeks collaborations with its suppliers to benefit from circular activities. The cutting fluid used in the company’s machining centers is an excellent example. Renault asked the supplier to not only supply the cutting fluid, but also maintenance and waste disposal services. The supplier then reengineered the cutting fluid and usage process, yielding 20% of ownership cost reduction and 90% less discharge volume which become savings in waste treatment.

**New Battery Ownership Model:** Renault was the first car manufacturer to lease batteries for its electrical vehicles. Renault’s batteries are now fully traceable to enhance closed-loop collection rates for recycling.

### 3.1 Circular Value Creation

Value creation or economic realization in circular economy may be categorized into at least four models.

- **Reuse, Refurbishing, and Remanufacturing:** These simple activities have proven to yield fast and substantial saving in practice. Reuse, refurbishing, and remanufacturing often lead to less materials to process; thus they require less energy and water, and discharge less waste. These footprints are shared throughout the product’s useful life. Associated externalities such as greenhouse gasses and environmental toxicity are also reduced. With less utility usage and waste treatment, cost saving could be realized.
• **Longer Circularity:** The idea of longer circularity is to maximize the life of the product in every cycle in order to avoid new product creation. A new product ownership model can encourage repair, reuse, or remanufacture actions of the new owner to extend the life expectancy of the product. Second-hand apparel is an example of prolonging product life cycle through change of ownership.

• **Cascaded Usage:** Once a product reaches its maximum usage in one function, it may be transformed or reused in another function. Fabric made from recycled plastic that is earlier mentioned is one example of a cascaded use. Another example is cotton clothing which is now reused as a substitute for virgin materials in fiber-filled upholstery.

• **Pure Inputs:** Uncontaminated materials increase collection efficiency and reuse ratio. Quality used materials are also easier to processed and recycled which helps increasing material productivity and extending material longevity. Collection of uncontaminated materials is still a challenging task and is driven by the market price mechanism where uncontaminated materials are priced higher than those contaminated ones. However, in the future, the used material collection could be executed more effectively through digital technologies and tracking information.

Noted that there are still the three flows (materials, information, and fund) in the circular supply chain but in certain areas, they are utilized for a different purpose, so-called Repurpose. For example, the data from product traceability which was difficult to trace from the customers is now used by the product manufacturer for repair and maintenance due to change of ownership in the business model. Financial benefits could be created and captured through applications of each model or their combinations. With the current technologies, most products are incinerated or put into landfill at the end of their useful lives (as shown in Fig. 3). With better technologies and changes in customer behavior, these burdens to our environment could be alleviated or completely eliminated.

### 3.2 Energy Cycle and Bio-Base Materials

An important driver of circular economy is renewable sources of energy such as solar, wind, wave, and biomass which in return significantly save energy cost for goods production. The cost of solar PV based electricity is now less expensive than that produced by fossil fuel since 2012, and the price continues to drop. In agricultural-based regions, organic wastes are processed through anaerobic digestion to produce biogas, usable to make heat, steam, and electricity which are utilized in postharvest production of several agro-industries.

Cassava starch production, for instance, has used its bio-base wastes to generate biogas, produce fertilizer, and mix with other ingredients in animal feed. The biogas obtained is processed to produce heat for the drying process, as well as to generate electricity to power the production plant. A similar practice is seen in the canned pineapple industry. The skin of fresh pineapples and pineapple cores are used to
produce methane (biogas). The wastewater collected from the pineapple canning processes is mixed with microorganisms to produce liquid fertilizer that is sometimes given back for no cost to neighboring pineapple farmers and communities. From these examples, the energy needed to power the economic cycle can at least partially be migrated to more bio-nutrient sources to decrease fossil fuel dependency and increase system resilience. Circularity of biological materials to the biosphere are usually preferred over technical materials which are more difficult to decompose.

Through digital technologies and regulation changes, it is now possible to exchange and/or trade energy with a local network of energy producers, consumers, and prosumers (an entity that behaves as a producer at one instance and a consumer at another instance) in many parts of the world. One such technology is virtual power plant (VPP). Through VPP, an energy producer in a sunny area may sell excess electricity to those in shady ones; or an agro-business may sell its biogas surplus during the harvest season but buy other forms of energy during other periods of the year. VPP allows community energy trade without having to establish large power plants. Large power generation plants are not so welcome nowadays as they often lead to local pollutions to nearby communities.

3.3 Post-consumption Collection Schemes

After products are used or reach the end of the useful life, they are discarded. To further reuse the products or certain parts of them, they need to be collected. There
are several schemes to systemically gather these post-consumption products. The followings are some examples of the collection schemes.

- **Advanced deposit fee**: When a product is purchased, there could be a fee charged at the price of the product. The fee is refunded to the customer only when the used product is deposited to a collection center such as a supermarket in the right condition. This collection scheme is often used with beverage cans and plastic bottles.

- **Take-back program**: In some countries, the manufacturers of certain products are required by law to take back the used products. For examples, waste electrical and electronic equipment (WEEE) and batteries in the European Union need to be collected by the producers because they may contain substances that are harmful to human health or have negative impacts to the environment. This legislation initiative is a part of extended producer responsibility (EPR) aiming to increase product recovery by passing the responsibility to the producers or polluters.

- **Trade-in or rebate**: Products that reach the end of their useful lives could sometimes be exchanged, or so-called traded in, for some discount to purchase new products. Although the discount may be devised primarily to attract sales, the used products get collected and treated. The returned products are processed to lessen effects on the environment and are sometimes recycled to make new products. Examples of products that have used this collection scheme are used clothes and mobile phones.

- **Pick-up system**: Household wastes are often seen using this collection scheme where the wastes are collected from customer locations in exchange for some fee. The collected wastes are then transported to local municipals to be sorted, treated, or sent to landfill locations.

- **Public recycling facility**: In some areas, the consumers are responsible to deposit a certain used products at a designated public recycling facility. The recycling service can be provided at no cost or for some small fee. The returned products get recycled at the center or sent out to other special recycling facilities.

The next section provides basic building blocks of the circular economy concept and suggests certain assessment guidelines.

### 4 Circular Economy Building Blocks and Measures

It is important to understand factors that influence the success of circular economy in existing organizations so that these enabling factors can be imitated and amplified in other firms. From the literature, key building blocks of circular economy can be grouped as follows.

**Business and product design**: Identify value creation, value capture, and value distribution in a given business context. Broader business models should be explored such as a service or performance-based one, value-added service, product return with intended incentive, and cascaded use of products.
Circular design: Identify means to extend the useful life of the products. Certain techniques can be deployed such as design for easy end-of-life disassembly and sorting, eco-design, standardized components, innovative ways to reutilize by-products and wastes. Reengineering of materials in certain applications can prolong material recycling ability.

Forward and reverse supply chain: Identifies operations that contribute to efficiency and effectiveness in forward and reverse chain such as delivery logistics, customer services, returned product sorting, green purchasing, material leakage points, and risk assessment. These activities are potential cost savings, enhancing product collection and treatment system, as well as effective towards end-of-life product services.

Environmental and societal consideration: Consider environmental and social issues in business strategies and operations. These issues include health of both employees and communities, population growth, job creation, climate change, quality agriculture, conservation of renewable sources, and customer awareness. Environmental and social issue inclusion make circular economy more sustainable beyond material circularity and profit-making in traditional business.

System and infrastructure: Enable the system through digital transformation, new forms of partnerships and collaborations. Use new regulations as incentives to internally change the organization and rethink organizational characteristics and financial models.

Several instruments and models could be deployed to promote circular economy. The next issue is to assess how well the organization performs under the context of circular economy. There exist several ideas to measure the CE performances such as the following metrics (Table 1).

These metrics are not exhaustive. They are merely examples of measures that can be used to benchmark with other organizations. The user should be selective of the measures or develop new ones to fit the context of the organization. For instance, from the Google Data Center example, the company optimizes end-of-life or servers based on the total cost of ownership instead of industry accounting standard. This keeps Google stay technologically competitive and yet economical.

Although there are several metrics for assessing circularity, economic value is one of the most common metrics. Economic values may not account for externality costs in some products, but these values could at least signal relative scarcity. The economic value could be estimated in several ways, but a simple one is from the market prices.

For a used product, it is possible that only certain parts or a fraction could be recirculated. Let $c$ be product-level circularity, then the product circularity can be expressed from its economic value as

$$c = \frac{\text{economic value of recirculated parts}}{\text{economic value of all parts}} \quad (1)$$

We may think of a product as consisting many parts. Some parts are recirculatable ($r$), while the others are non-recirculatable ($n$). For any product or part $i$, then
Table 1  Circular supply chain metrics

| Category                          | Metric detail                                                                                                                                 |
|-----------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------|
| Resource efficiency               | Measures relating to part/product over its lifetime  
**Metrics:** recycling efficiency, product longevity, supply risk and scarcity, conservation of value, value change and retention, resource productivity, energy efficiency, life cycle assessment, net material saving |
| Material stocks and flows         | Measures relating to resources and usage  
**Metrics:** stock availability and concentration, down-cycling quality loss, recycling/remanufacturing potentials, resource productivity, cascading use, product traceability |
| Product-centric and environmental impacts | Measures relating to product, waste, and environment concerns  
**Metrics:** amount of virgin stock and secondary materials, process inputs, product toxicity, cradle-to-cradle certification, eco-labeling, waste disposal, greenhouse gas emission, reuse/recycling complexity, pollution reduction, shift to renewable energy, land productivity and soil health |
| Economic and other performances  | Measures relating to product, waste, and environment concerns  
**Metrics:** financial growth, investment recovery, job creation, health impacts to animal and public, take-back rate, resource sharing, information exchange among partners (trust level), technology assisted circulation, price volatility reduction |

\[
 c_i = \frac{r_i}{r_i + n_i} \quad (2)
\]

The term \( r_i + n_i \) can be thought of the value of a new product (or part). Services involved in producing the product may be considered through the non-recirculatable term in Eq. (2). Using this assessment metric, the product circularity is always between 0 and 1.

**Example**  A laser printer toner cartridge consists of a plastic casing and ink powder. The plastic casing can be reused after the cartridge is depleted, but the ink is not. Suppose that to refill the reused cartridge it requires some labor work of $5 per cartridge. The plastic casing is worth $40 each and the ink powder $30 per cartridge. Then the circularity of this cartridge is

\[
 c = \frac{\text{plastic casing cost}}{\text{plastic casing cost} + (\text{ink powder cost} + \text{labor cost})} = \frac{40}{40 + (30 + 5)} = 0.533.
\]
In addition to economic and environmental impacts of circular economy, social implications are perhaps the most difficult aspect to measure. Corporate reports usually account for immediate financial consequences in their financial statements. There is yet a diverse debate in the academic literature of appropriate methodologies to include social externalities in financial values in corporate financial reports. For example, food waste in inner-city areas that are once unwanted could be turned into energy for urban families through the circular economy concept. It does not only reduce negative environmental externalities, but potentially improve the resiliency of the communities in being more energy independent. Managing all the food waste can be a challenge, but at the same time, it creates business opportunities for individuals or possibly the entire communities.

Methods to explicitly measure, collect, and analyze data on social impacts are still evolving. The consequences remain in including these social externalities in the fund flow of the circular supply chain. It is possible that social externalities are contextual depending on activities, communities, industries, and the risks involved. Without social impacts measured, however, assessment of circular supply chain is not completed, and the full potentials of circular supply chain may not be obtained. The benefits of circular supply chain could be underestimated or completely ignored, particularly the social implications.

5 Circular Supply Chain Implementation Strategies

To execute circular economy, strategic activities must be established. Clear plan of action is a fundamental requirement needed in the organization. A starting action may be to identify certain materials, understand the flows of materials, information, and fund, and determine material leakage points together with their quantities—which from another angle could be considered as potential benefits. Then map out relating operations, barriers, and technological landscape to explore the most promising areas. Product and material usage may need to be redefined from the perspective of intended use, alternative use, and use period. This can help create new businesses or facilitate replacement and financial return periods. Improvement of existing operations should be continually executed, while identifying stakeholders to support short, medium, and long-term goals.

Once there is a clear plan of action, enabling mechanisms can start. The reverse loop may need to be set up if it does not already exist. Select the material from a preferred short list that is suitable for the circularity. Identify the right partners and agree on a business model that the benefits are shared. Follow mutually agreed roadmap among the partners. Quantification of economic impacts may begin with material flow or material circulation in comparison to no circularity. A focus could be on inputs such as material, energy, water, labor, and/or outputs such as wastes and carbon emissions. Assessment may include innovation development and leakage point reduction.
Several successful companies who implement circular economy philosophy have expanded their business from suppliers to business solution providers by which idle assets are better utilized (see Philips Lighting as a Service for an example). Ownership and take-back models are being rethought over or taken control in the form of rental and leasing. This allows high-cost products to compete with low-cost ones over traditional sale model. At the same time, the products or assets are better utilized and the cost is shared among the parties including the customers to gain better services for the customers, better quality of returned products to the producer, as well as a more stable stream of revenue to the involving partners.

Collaboration and sharing can accelerate circular economy. Collaborative platforms may allow people to exchange intangible assets such as skills, experience, knowledge, and space. These platforms could be a marketplace for recruitment and outsourcing small jobs. Redistributive markets such as eBay and Craigslist are also possible through internet technologies. These virtual markets reduce shopper’s travel trip and potentially save carbon emission. Information technology is a key enabler to mobilize circular economy in many industries. Reverse material data and Big Data analysis can be utilized to improve material circularity. Innovative materials that can endure circularity longer may need to be engineered with perhaps external experts or new partners.

A connection between digitization and circular economy is becoming prominent in recent years. We have seen that digital technologies have been adopted in several functions of the supply chain such as in inventory and warehouse management, material purchasing, enterprise resource planning (ERP), freight management, and financial transaction record keeping. Modern digital technologies may include machine learning and predictive analysis to project the future outcomes or detect certain behaviors in that function. For circular supply chain, in many cases, it is the digital technologies that initiate changes in the infrastructure that in turn facilitates circular supply chain transformation of the company. Digitization in circular supply chain is often used to connect data among suppliers, service providers, customers, and their devices. Data storage and data access could be executed through cloud. This can greatly benefit companies that operate in several locations to be able to share, synchronize, and analyze the same set of data in real time or almost real time. Consequently, once the data access and transparency is improved the decision-making of the entire organization can be made faster and with the most updated information. This would improve operational efficiency and optimize business impact.

Several technologies and digitization of supply chain operations are gaining popularity, including blockchain, big data, data visualization, e-commerce platform, smart mobility, cloud service, virtual reality, augmented reality, artificial intelligence, business intelligence, and optimization. Whichever of these technologies are selected, they should improve at least some of the circular supply chain activities such as product design, target customer attraction, product tracking, technical and maintenance support, and end-of-life activities. An area of concern for the digitized circular supply chain is data security. While sharing of data enables collaboration in the supply chain, some data may need to be securely isolated and shared only when necessary for
the purpose of competitive advantages. Data security measures and data privacy policies should be put in place when digitization is implemented. Ethical issues should be clearly discussed early on when data digitization is employed to a personal or community level.

**Philips Lighting as a Service [2]**

Philips became a pioneer who shifted from selling light bulbs to lighting as a service provider. Philips’ business models redefine the notion of access versus ownership of lighting systems, but the business model was in fact generated from circular economy principles. Through the service, Philips install, maintain, manage end-of-life light bulbs. The customers no longer need to invest in the lighting system upfront, nor stocking light bulbs for emergency replacement. Since Philips retains the ownership of the products, this allows easier and better management of discarded light bulbs for recycling and reclaiming valuable materials. The lighting services include rental, leasing, pay-per-use, and pay-per-service models.

The role of the consumers in circular supply chain is another area that is largely unexplored and requires further investigation. Circular products need to be designed in such a way that they are appealing to general consumers. Educating the general public of the quality of the circular products, as well as marketing and pricing, are all essential to move circular economy forward and make the whole supply chain more sustainable.

6 Conclusion

Climate change and environmental conditions are posting unprecedented threats to the world’s growing population. It is our duty to resolve those threats. Circular economy is offering a solution to alleviate those threats while being economically viable. Its fundamental concept is to maximize material utilization to reduce the need for virgin material and maintain environmental balance, and yet continue economic growth.

Several companies have adopted circular economy throughout their supply chains and found success. Examples of different activities and areas where other companies should concentrate on circular economy are given in the chapter. These could be a starting point for novice circular economy adopters. Nevertheless, the context of the individual business should also be considered and adaptation may be needed. Several measures to assess how well the parties in the circular supply chain are performing are suggested, although they too are context-dependent. Sectors that have already realized benefits from circular economy through their supply chains include packaging, food, electronic and electrical equipment, transport, furniture, buildings, and construction. While new problems require innovative solutions and determination to overcome, businesses and customers together need to be resolute in
mobilizing circular economy and circular supply chain to realize their true potentials and maintain the balance of our environment for future generations.

**Questions**

1. Compare the traditional and circular supply chain models in terms of involving parties, advantages and disadvantages, ease of implementation, etc.
2. Select an existing supply chain. Then apply the circular supply chain concept to it.
   (a) Discuss different business models, material leakage points, material flows, etc.
   (b) If the selected supply chain is already a circular supply chain, try to improve it based on different metrics.
   (c) Propose technologies that can improve the circular supply chain.
3. Select a product. Propose how to improve its collection and recyclability. Assess economic, environmental, and/or social impacts of your proposed solution.
4. Recommend relevant digital technologies that may improve the circularity of a product. Different technologies may be utilized for different parts of the supply chain of the product.
5. It is possible that a disruptive event such as a natural disaster or global pandemic (COVID-19 for instance) can affect a circular supply chain. Suggest preventive or corrective measures to alleviate impacts from such disruptive event.
6. It is still a debatable topic in how social externalities be measured in financial terms.
   (a) Discuss advantages and disadvantages of different assessment methods of social externalities. Select one method (or create one) and suggest how it should be integrated into circular supply chain, particularly in the financial flow.
   (b) Are there any business opportunities from the lack or incomplete assessment of social externalities in circular supply chain?

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