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2022 (First Year) International Trend Research Report on Circular Economy (CE) Policy/Standard and Case Studies of Advanced CE Companies

Grant-in-aid for Scientific Research, Basic research (B), Japan
"Development, Empirical Research and Dissemination of New Theories and System Techniques for Circular Economy (CE) to Meet SDGs Goal 12; Producer and Consumer Responsibility"
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2022 (1st Year of Research Period) Research Framework of New Theories and System Techniques for Circular Economy (CE):
Based on International Trend Researches on CE Policy/Standard and Case Studies of Advanced CE Companies

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1. Introduction

In the past, the Japanese manufacturing industry was primarily based on the business model of selling off the products introduced into the market and the 3R tactics (reuse, reduce, and recycle) for to follow up on waste disposal. "Target 12.3: Food loss reduction" and "Target 12.5: Waste reduction" included in " SDGs Goal 12: Producer and consumer responsibility" are related to the circular economy (CE); Target 12.5 stipulates that the targeted social issues should be resolved on a global scale by 2030. The European Union's (EU) CE Commission has defined CE as follows: "CE is an economic policy that will enhance new competitiveness by creating new business opportunities and innovative and efficient production methods and consumption styles, protecting companies from resource depletion and price volatility".

Our research theme was selected as "development, empirical research, and dissemination of new theories and system techniques of the circular economy (CE) to meet the SDGs Goal 12: Producer and consumer responsibility" (Principal investigator: Kin'ya Tamaki, for Grant-in-aid for Scientific Research, Basic research (B), Japan).

Therefore, the first purpose of this research paper is to delineate the research framework and to research and develop five new theories and system techniques as described below:
(1) Multi-generational and CE value chain management (CE-VCM)
(2) Cyclical resource supply and resource collection
(3) CE product planning and digital marketing
(4) Smart product and service lifecycle design
(5) Sharing platform and application software compatible with CE-VCM

The second purpose is to explore how to proceed international trend research concerning CE policies and standards in each area and country (Japan, EU, USA) and case studies of advanced CE companies in each industry such as those related to automobiles, electronics and devices, construction, food and agriculture, chemicals and materials, and software and platforms.

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2. CE Principles and "Butterfly Model" by Ellen Mac Arthur Foundation

2.1 CE Definition and CE Principles

The Ellen Mac Arthur Foundation (EMF) founded in 2010 is promoting the concepts of the circular economy and the sustainable transition. The EMF defines CE as: "a system solution framework that tackles global challenges like climate change, biodiversity loss, waste, and pollution. It is based on three principles, driven by design: eliminate waste and pollution, circulate products and materials (at their highest value), and regenerate nature" [Ellen Mac Arthur Foundation]. In addition, the EMF presents the "Three Principles of the Circular Economy":

- Product design in a manner that does not generate waste and pollution
- Continue to use products and raw materials
- Regenerate natural systems

2.2 The "Biological Cycle" and "Technical Cycle" in the "Butterfly Model"

With the aim of realizing the aforementioned CE principles, the EMF theorized the "butterfly model" [Ellen Mac Arthur Foundation, 2013] which explained how the flows of both "biological cycle" and "technological cycle" can be maintaining products and resources at their highest value, through regeneration, repair, reuse, refurbish, and only lastly recycle (**Figure 2.1**).

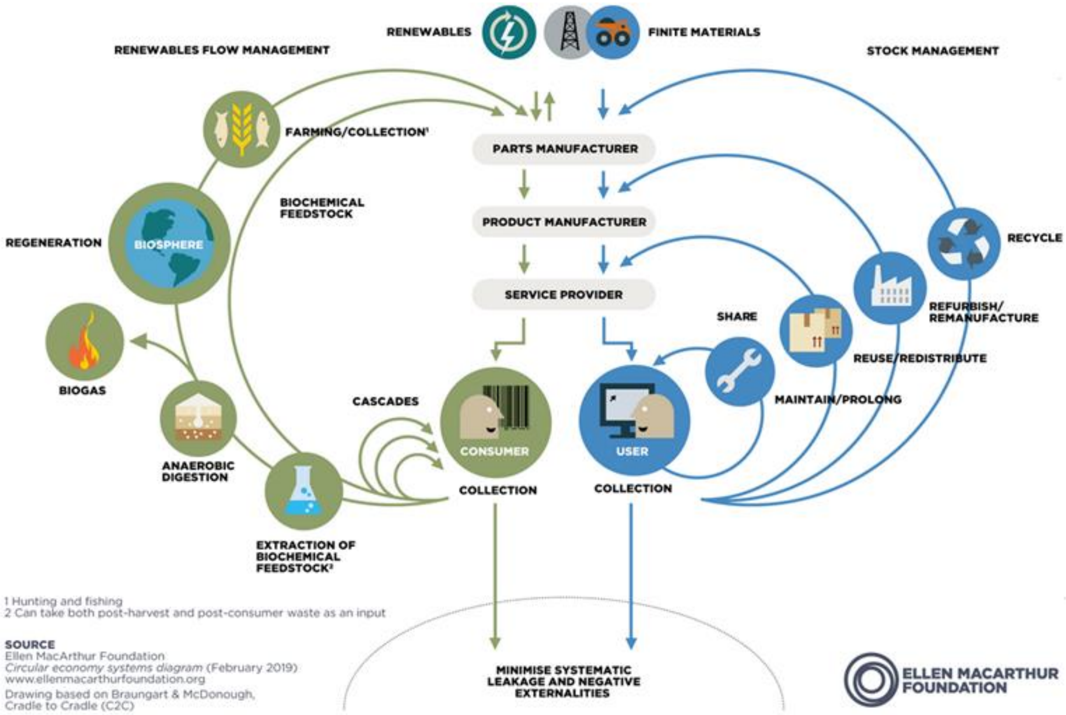

Figure 2.1 The "butterfly model" by Ellen Mac Arthur Foundation (Ellen Mac Arthur Foundation, 2013)

The central part of the figure expresses the conventional "linear model (procurement, production and disposal of resources)". This linear model is used by consumers through a series of corporate activities that procure and invest resources, process and manufacture, and provide services. After consumer use, the disposal of resources is incinerated or landfilled.

Renewable resources in the "biological cycle" cannot move through the cycle indefinitely. It gradually deteriorates as it undergoes cycles using resources. This process of recycling renewable resources as their original quality deteriorates are called "cascade recycling." It is nearly impossible for a single company to achieve such cascading recycling.

The cycle should then be repeated several times. When the resource finally becomes unusable, it will eventually return to nature. It can be returned to the soil through biodegradation or composting, and organic waste can be converted into biogas and can be used as energy. When it returns to the soil, it creates circulation by generating new plants and organisms. However, if the product itself contains harmful chemical substances, the above will be extremely difficult.

In the "technological cycle", it is fundamental to use depleted resources in economic activities without waste and to continue to circulate them. Since it requires less energy, resources, and labor to newly input resources, they should be circulated from the inside as much as possible (referred to as the "inner loop").

Specifically, one must first eliminate waste by maintaining and repairing and using it for a long time or by sharing it. When the original owner no longer uses it, it will be reused and redistributed, which generates CO_2 and requires new energy in the form of fuel consumption.

Next, when reuse and redistribution are no longer possible, the product that has been used once is disassembled, cleaned or otherwise maintained, and then reassembled into a product (remanufacturing and refurbishment).

Finally, when it becomes impossible to remanufacture, it will be recycled as the outermost loop. In other words, recycling involves the return from old raw materials to new remake parts and products.

Therefore, at the product design stage, it is important to apply about "system technique for product life cycle design (described later)" that allows the inner loop to flow as much as possible.

3. "CRADLE TO CRADLE CERTIFIED®" by Cradle to Cradle Products Innovation Institute

It is now possible to acquire "Cradle to Cradle certification (CRADLE TO CRADLE CERTIFIED®)" based on how well a company can create a recycling cycle and whether it incorporates products that meet the conditions. The certification system is operated by the Environmental Protection Promotion Agency (EPEA) established in Hamburg, Germany [Cradle to Cradle Products Innovation Institute, 2021]. EPEA evaluates applicants in five stages, namely Basic, Bronze, Silver, Gold, and Platinum, after carefully examining the degree to which the cyclical cycle is incorporated into the product design and manufacturing process.

To receive "CRADLE TO CRADLE CERTIFIED® (C2C)" conditions, the following conditions must be met:

1) Health of raw materials: Consider the environment and use minimal chemical substances.
2) Reuse of raw materials and parts: Reuse of parts and recycling as raw materials after the product has been used.
3) Use of natural energy and carbon management: Use renewable energy in production and work to reduce greenhouse gas emissions.
4) Water Stewardship: Do not pollute water during production.
5) Social fairness: Respect people and the environment, from raw material procurement to production.

4. CE Policy Trends in EU

4.1 Eco-Design Working Plan

The "Eco-design working plan (2016-2019)" was issued in November 2016, with the purpose of identifying working commissions' priorities under eco-design and energy labelling [European Commission, 2016]. In Europe, the eco-design and energy labelling directive are framework directives; therefore, they should be transposed by Member States, which establish binding requirements that are specific to each product group. Working plans are designed to help identify categories of products to be investigated in depth in the upcoming three years and for which new measures can be prepared.

Eco-design directive and energy labelling measures have been then modified, including new material efficiency requirements, such as ease of repair and the facilitation of end-of-life treatment. Beyond these mandatory aspects, voluntary tools have been developed such as the EU Ecolabel and the Green Public Procurement criteria. In October 2019, 10 eco-design implementing regulations were adopted specially concerning household appliances such as refrigerators, washing machines, dishwashers and televisions.

4.2 EU Action Plan for Circular Economy (CE Package)

Starting in 2015, the first "circular economy action plan" was adopted in previous initiatives promoted by the European Commission. This initial plan included measures stimulating the Europe's transition towards a circular economy while fostering sustainable economic growth and the generation of new jobs [European Commission, 2015]. Fifty-four actions were included in the plan, and after three years of implementation, all of them had been achieved, even if the work continues beyond 2019 for some actions. Actions were related to the entire life cycle and included details of different phases of the production and consumption process. The actions were divided according to the topic they mainly refer to and thus included the following: production, consumption, waste management, market for secondary raw materials, and sectorial actions concerning some on strategic sectors (e.g., plastic, food waste, critical raw materials, construction and demolition, biomass and bio-based materials, innovation and investments, and monitoring).

4.3 New Circular Economy Action Plan

As one of the main pillars of the European Green Deal, in March 2020, the European Commission adopted the "New Circular Economy Action Plan" [European Commission, 2020]. The new action plan is composed of thirty-five actions to be implemented in the timeframe 2020-2023; it focuses on different areas from the previous action plan. The key actions are listed under seven macro-areas that correspond to as many overall goals and targets: a sustainable product policy framework; key product value chains; "less waste more value;" making the circular economy work for people, regions, and cities; crosscutting actions; leading efforts at a global level; and monitoring progress.

The design of sustainable products is intended to help broaden the eco-design directive beyond energy-related products, thereby improving product durability, reusability, upgradability and reparability and increasing the amount of recycled content. Prioritized areas of intervention include electronics, textiles and ICT (Information and Communication Technology).

In the three years since the adoption of the circular economy action plan, many results have been achieved. The Commission adopted a proposal for a new regulation regarding sustainable batteries (2020); a Global Alliance on Circular Economy and Resource Efficiency (GACERE) was launched in 2021; and new proposals about organic pollutants in wase and waste shipments were adopted.

5. CE International Standards /TC 323

International standards related to circular economy are still under development by ISO/TC（Technical Committee）323 Secretariat. The ISO 59000 series of documents (**Figure 5.1**) are designed to deepen the understanding of the circular economy and to support its implementation and measurement.

Figure 5.1 The ISO 59000 series of documents [ISO/CD 59004]

5.1 ISO/CD 59004 - Circular Economy – Terminology, Principles and Guidance for Implementation

This document defines key terminology, establishes a circular economy vision and principles for organizations, and provides guidance, including possible actions, for implementation [ISO/CD 59004]. It is intended to be used by organizations seeking to understand and commit or contribute to a circular economy while contributing to sustainable development. These organizations can be either private or public, acting individually or collectively, regardless of type or size, and located in any jurisdiction, or position within a specific value chain or value network

5.2 ISO/CD 59010 - Circular Economy — Guidance on the Transition of Business Models and Value Networks

The circular economy and related business models have emerged as a promising strategy, thus gaining increased attention and support in society. Circular business models provide many opportunities that are more sustainable than existing linear models. In addition to its potential environmental benefits, studies have demonstrated that the circular economy offers opportunities worth trillions of USD, including job creation, which c builds resiliency in national and international economies.

During the development of this document, a survey of existing business practices and guidance was conducted to characterize the status quo and to obtain insight into future directions [ISO/CD 59010]. The survey results have been published as ISO TR 59032, thus providing wide-ranging opportunities for transformative change in business models and supply networks. This document is divided into several clauses and their respective sub-clauses. The **Figure 5.2** shows their relationships as well.

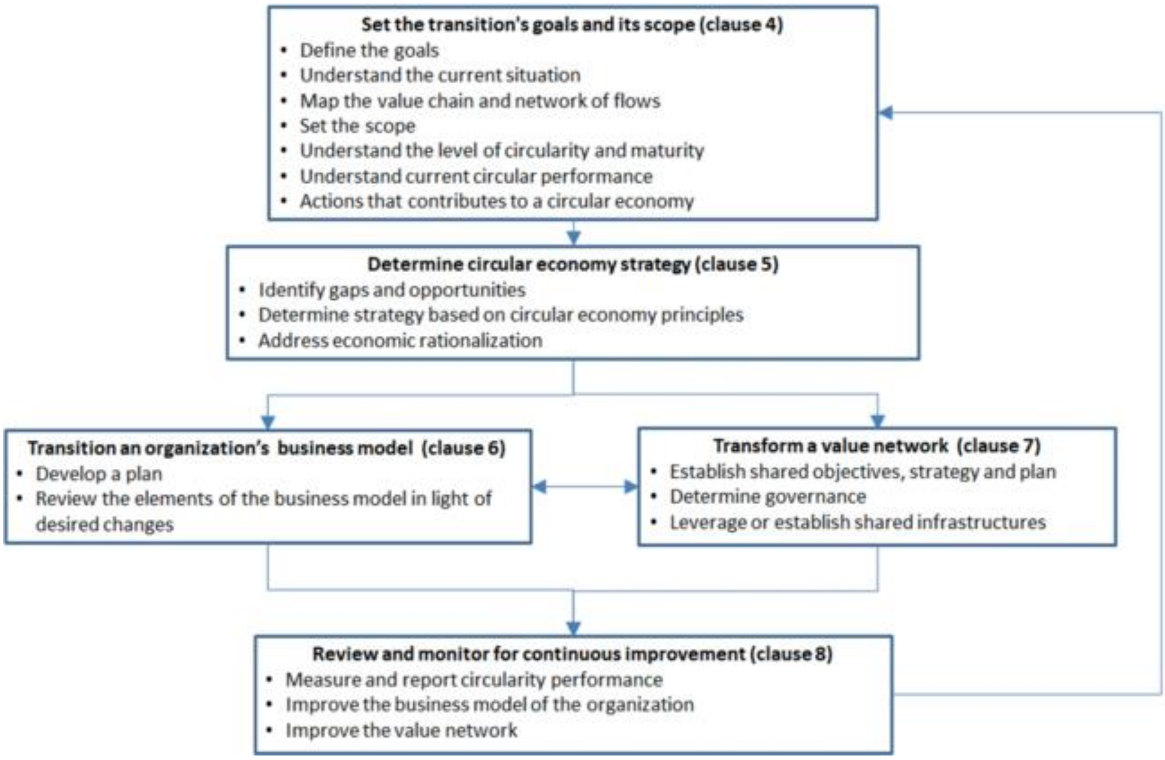

Figure 5.2 The structure of this document: "ISO/CD 59010: Guidance on the transition of business models and value networks" [ISO/CD 59010]

5.3 ISO/CD 59020 - Circular Economy — Measuring and Assessing Circularity

This document specifies a framework for organizations to measure and assess circularity, thereby enabling those organizations to contribute to sustainable development [ISO/CD 59020].

The framework is applicable to multiple levels of an economic system, ranging from the regional, inter-organizational, and organizational level to the product level. The framework provides guidance on how the circularity performance of an economic system can be objectively, comprehensively, and reliably measured and assessed using circularity indicators and complementary methods. The framework can be used to determine the effectiveness of circular actions executed by public and private organizations. The purpose of the standard is to assist organizations in the collection of necessary information to enable circular economic practices that minimize resource use, enable a circular flow of resources and contribute to sustainable development.

The framework can account for social, environmental, and economic impacts when assessing circularity performance by allowing input from various complementary methods.

5.4 ISO/CD TR 59031 - Circular Economy – Performance-Based Approach – Analysis of Cases Studies

*Status: Under development

5.5 ISO/CD TR 59032 - Circular Economy – Review of Business Model Implementation
*Status: Under development

5.6 ISO/CD 59040 - Circular Economy – Product Circularity Data Sheet
*Status: Under development

The document provides a general methodology for improving the accuracy and completeness of circular economy-related information based on the usage of a "Product Circularity Data Sheet" when acquiring or supplying products [ISO/CD 59040].

This general methodology contains then a set of requirements that need to be established by an organization aiming to use the concerned data sheet when acquiring or supplying products, which also includes the trusted reporting and exchanging of circular economy-related information. The document also provides guidance regarding the definition and sharing of the Product Circularity Data Sheet in relation to the type, content and format of information to be provided.

This guidance and these requirements are intended to be applicable to all organizations, regardless of type, size and nature. These requirements implement a qualitative approach to business-to-business data exchange, to ensure inclusivity in relation to small and medium businesses or enterprises, and to protect confidential information.

6. Trend Surveys Regarding CE Policy and Industry Case Study in Japan

6.1 "Circular Economy Vision 2020" Compiled by the Ministry of Economy, Trade and Industry

(1) Background

With the aim to present basic future directions of policies for a circular economy, the Ministry of Economy, Trade and Industry (METI) conducted surveys on the current state of challenges related to resource circulation at home and abroad, and analyzed the results. As part of this effort, the "Study Group on Circular Economy Vision" held repeated discussions since July 2018 and compiled the discussion results into a report titled "Circular Economy Vision 2020" [METI, 2020].

(2) Outline of the Circular Economy Vision

In addition to the need to transform to a circular economy, Japan should consider development of digital technologies and growing demand for environmental considerations from markets and society as new drivers. In line with this, all industries in Japan should regard this transformation as a new business opportunity that can guide their businesses to a "virtuous cycle of the environment and growth:" this should be considered as a marked shift from the existing 3Rs initiative as a measure for addressing waste and the environment, to new business models with higher circularity as management and business strategies.

With the aim to encourage Japanese companies to exercise their strengths related to mid to long-term industrial competitiveness by advancing their efforts in the 3Rs program, METI compiled the Circular Economy Vision 2020 with three different viewpoints in mind:
[i] shift to new business models with higher circularity,:
[ii] acquire appropriate evaluation from the market and society: and
[iii] establish a resilient resource circulation system early to present Japan's basic policy directions for a circular economy.

In the following, the "[i] shift to new business models with higher circularity" is discussed in particular.

(3) [i] Shift to new business models with higher circularity

To create a highly cyclical business, it is necessary to make various efforts beyond the traditional 3Rs. It is essential for companies to select appropriate recycling-oriented initiatives according to each industry at every stage of design, production, use, and disposal, and to design circularity throughout the entire product life cycle.

1) Artery industry: Toward a recycling industry that ensures circularity and leads recycling and towards the shift to a circular economy within all arterial industries, including the manufacturing industry, the distribution industry, and even service platforms that utilize digital technology,

- In addition to the role of the generator of industrial waste (responsibility of the generator).
- It is necessary to design highly cyclical products and business models and build a circulation system that includes recycling.

As described above, it is important to place each used product on the most appropriate collection route and reuse or recycle it in the most appropriate manner, according to its value chain, properties, and emission sources.

- Distribution and collection while maintaining product ownership through leasing, sharing, subscription.
- Efforts should be made to circulate resources throughout the product lifecycle via voluntary collection of used products and the establishment of recycling routes in cooperation with venous industries.

2) Venous industry: Shift from recycling industry to resourcing industry

For daily necessity products that are widely distributed among end consumers, it is difficult to predict collection times and discharge locations. For this reason, the venous industry should collect these various used products over a wide area, and stably supply high-quality recycled materials by actively utilizing automatic sorting technology.

It is important to expand the use of recycled materials by facilitating communication between the arteries and veins regarding the quality, origin, and product characteristics that are necessary when deciding whether to buy or sell materials based on these quality standards and usage standards. Through these efforts, it is expected that the cost of recycled materials will decrease.

6.2 Japan Partnership for Circular Economy (J4CE)

(1) Introduction

The Japan Partnership for Circular Economy (J4CE) was founded on March 2021 by the Japanese Ministry of the Environment (MOE), Ministry of Economy, Trade and Industry (METI), and Japan Business Federation (Keidanren). J4CE works to strengthen public-private partnerships to foster understanding of the circular economy among a wide range of stakeholders, including companies in Japan, and to promote initiatives in response to the accelerating global trend toward a circular economy.

The launch of J4CE attracted wide attention and more than 150 companies and industrial organizations had joined J4CE as of September 2022. Approximately 160 cases and initiatives have been submitted by participating companies and organizations, and all these cases are introduced on the J4CE website. In September 2021, J4CE selected 28 noteworthy cases and initiatives and published a brochure entitled "Noteworthy Cases 2021 Edition." They were also actively involved in international outreach by distributing the brochure at a side event of COP26.

According to the UNEP International Resource Panel (IRP), the extraction and processing of natural resources into materials, fuels and food accounts for about half of all global GHG emissions (excluding climate impacts related to land use). In light of this, when preparing the 2022 edition of the "Noteworthy Cases," they selected cases related to and resource recycling in diverse industries, based on the recognition that promoting the circular economy is also important for advancing decarbonization [Keidanren, 2022].

J4CE hopes that the cases will make it widely known inside and outside Japan, that Japanese companies are promoting the circular economy through their excellent technologies, ideas and collaborations; they also aim to help promote the circular economy in Japan and around the world by further disseminating these efforts. Below is a table of contents for CE Noteworthy Cases by industry:

(2) Noteworthy Cases

Noteworthy Area 1: Steel

- Case 01; Steel is a Sustainable Material (Nippon Steel Corporation)
- Case 02; Effective Use of Steel Slag (Same as above)
- Case 03; Building a Recycling Scheme for Scrap Iron (Panasonic Corporation)

Noteworthy Area 2: Non-Ferrous Metals

- Case 04; Recovering Various Types of Valuable Metals Using a Large-scale Smelting and Recycling Complex (DOWA HOLDINGS CO., LTD.)
- Case 05; Processing of Recycled Materials in the Copper Smelting and Refining Business (JX Nippon Mining & Metals Corporation)
- Case 06; Closed Loop Recycle of Lithium-ion Batteries (LiBs) (ENVIPRO HOLDINGS Inc.)

Noteworthy Area 3: Cement

- Case 07; Waste Utilization by Cement Industry (TAIHEIYO CEMENT CORPORATION)
- Case 08; Recycling of Lithium-ion Batteries (Same as above)
- Case 09; Recovery and Recycle System for Precious Metals in Municipal Solid Waste Incineration Residue (Same as above)

Noteworthy Area 4: Paper and Woody Resources

- Case 10; Production and Circulation of Woody Resources (Nippon Paper Industries Co., Ltd.)
- Case 11; Initiatives for Resource Recycling Business: Promote Collection and Recycling of Used Paper Cup Containers – (Same as above)
- Case 12; Development of New Biomass Material: Cellulose Nanofibre – (Same as above)
- Case 13; Towels Made from Japanese Cedar (NEBA Forestry Union, Nagano Prefecture)

Noteworthy Area 5: Bioplastics

- Case 14; Renewable Plant-Based Engineering Bioplastic "DURABIO" (Mitsubishi Chemical Corporation)
- Case 15; Bio-Based and Biodegradable Plastic "BioPBS™" for Agriculture Film (Same as above)
- Case 16; Renewable Plastics from 100% Bio-Based Hydrocarbons (Mitsui Chemicals, Inc.)
- Case 17; Eco-friendly Package "Biomass ECO CUP" (NISSIN FOODS HOLDINGS CO., LTD.)

Noteworthy Area 6: Collection and Recycling of Plastic

- Case 18; Blockchain-Based Digital Platform for Plastic Traceability (Asahi Kasei Corporation)
- Case 19; Collection of Used PET Bottles and Educative Activities for Bottle-to-Bottle Closed Loop Recycling (Japan Soft Drink Association (JSDA))
- Case 20; Collaborative Plastic Recycling Program Promoted by Consumers, Local Governments and Companies (Veolia Japan Group, Unilever Japan, Kao Corporation, The Procter & Gamble Company of Japan Limited, Lion Corporation)

Noteworthy Area 7: Recycling Technologies (Home Appliances, Plastic, Textile)

- Case 21; Automatic Picking System Using AI (Artificial Intelligence) (Association for Electric Home Appliances)
- Case 22; SORPLAS™, Sony's Proprietary Flame-Retardant Recycled Plastic with up to 99% Recycled Material Utilization Rate (Sony Group Corporation)
- Case 23; Chemical Recycling Technology of Polyester (Teijin Ltd., JGC HOLDINGS CORPORATION, ITOCHU Corporation)

Noteworthy Area 8: Formulating a Recycling Loop (Plastic, Food Waste)

- Case 24; Closed-Loop Recycling of Label Release Film (NEION Film Coatings Corp., TOYOBO CO., LTD., Shionogi Pharma Co., Ltd., TOPPAN INFOMEDIA CO., LTD., Mitsui Bussan Chemicals Co., Ltd.)
- Case 25; Self-Contained Food Recycling Loop (AEON Co., Ltd., DAIEI KANKYO Co., Ltd., AEON AGRI CREATE CO., LTD., AEON RETAIL Co., Ltd.｜The Daiei Inc.)
- Case 26; Yokohama Food Recycle Project (JFE Engineering Corp., J&T Recycling Corp., Urban Energy Corp., East Japan Railway Company, JR East Environment Access Co., Ltd., J Bio Food Recycle Corp.)

7. Research and Development Framework for New CE Theories and System Techniques

As mentioned above, our research theme encompasses the "development, empirical research and dissemination of and system techniques of the circular economy (CE) to meet the SDGs Goal 12 Producer and Consumer Responsibility" for Grant-in-Aid for Scientific Research, Basic research (B), Japan [Tamaki, 2022].

7.1 Framework for New CE Theories and System Techniques

The aforementioned first purpose is to present a research framework for research and development of five new theories and system techniques as described below (**Figure 7.1**):

(1) Multi-generational and CE value chain management (CE-VCM)

(2) Cyclical resource supply and resource collection

(3) CE product planning and digital marketing

(4) Smart product and service lifecycle design

(5) Sharing platform and application software compatible with CE-VCM

(1) Multi-generational and CE Value Chain Management

As illustrated in **Figure 7.1** above, after investigating CE policies, international standards, and trends, the first research issue to develop a multi-generational and recycling CE value chain management (referred to as "CE-VCM") reflected to the characteristics of each industry. With this CE-VCM as the central axis in **Figure 7.1**, four relevant research issues surrounding it are to establish and to develop "CE theories" and "CE system techniques" by full use of advanced technologies.

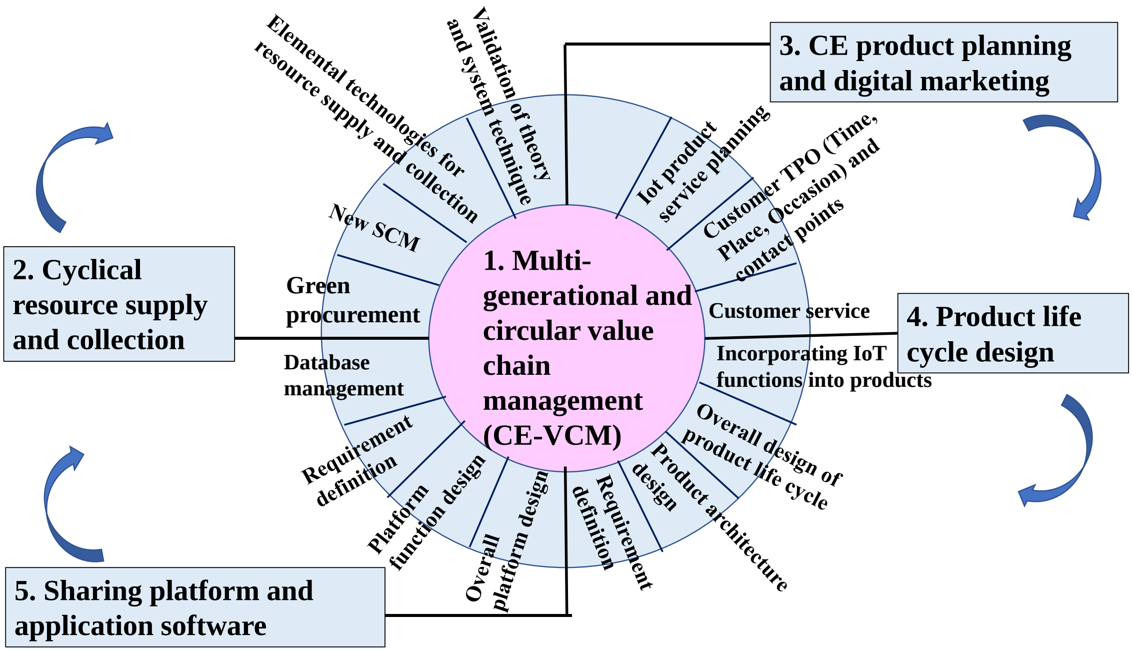

Figure 7.1 CE New Theories and System Techniques around CE-VCM [Tamaki, 2022]

The CE butterfly diagram mentioned above consists of a biological cycle and a technological cycle. The former "biological cycle" consists of product services and business processes that account for the utilization of renewable resources, the regeneration of resources in the natural world, and the extraction of biochemical raw materials from collected materials.

The latter "technical cycle" consists of stakeholders and business activities, such as recyclable resource supply, parts manufacturers, product manufacturers, customer service companies, resource recovery, and 3R.

As research issue 1, the CE-VCM based on product services mainly focus on the latter technical cycle. In addition, regarding the "CE-oriented future city development," we believe that the autonomous management of the city should mutually integrate the "biological cycle" and the "technical cycle".

The following key concepts should be considered when building the new CE-VCM model that reflects industry characteristics:

- To build CE-VCM that reflects a circulation model that can be connected to the next generation product service after surely collecting used product services, deviating from a single model that culminates in selling product services to customers.
- This CE-VCM consists of the following elements: CE-oriented supply chain management (SCM), stakeholder management responsible for each chain, and engineering chain related to the development and design of CE product services.
- To build a CE-VCM that realizes value co-creation that can continuously provide services that align with the lifestyle of each individual customer (one-to-one) after selling the product.
- At the final stage of one cycle of CE-VCM, the next CE-VCM builds a new business process model that can reliably collect old products from cooperative customers.
- To transcend conventional industrial classifications, and to form new industrial clusters that can realize CE-VCM across multiple industries, new CE industries and CE employment should be created.
- To enable "CE-oriented future city development," the "biological cycle" related to the primary industry and the "technological cycle" related to the secondary and tertiary industries should be mutually integrated. Through these, we can autonomously operate a town of local production for local consumption or local production for others consumption types.
- Towards "CE-oriented future city development", both the "biological cycle" related to the primary industry (agriculture, fishery, forestry), and the "technological cycle" related to the secondary (commerce) and tertiary industries (manufacturing industry) should be mutually integrated. The CE-oriented future city aims to autonomously operate with local production for local consumption or local production for others other market consumption.
- To establish a new CE impact evaluation index corresponding to SDGs Goal 12, namely “Production and consumption responsibility” and devise a new impact evaluation method corresponding to SDGs/ESG (Earth, Society, Governance) /CE.

(2) Cyclical Resource Supply and Resource Collection

Regarding "cyclical resource supply, collection, and recovery" methodology, after examining and reflecting various CE regulations and laws related to sustainable procurement, we will explore elemental technologies and verify the applicability and effectiveness of the developed methodology.

- Investigate trends in regulations and laws related to green procurement such as ISO20400 and sustainable procurement and OECD Due Diligence Guidelines
- Deviate from the “3R (reuse, reduce, recycle) model;" explore new supply chain management (SCM) and elemental technologies necessary for cyclical-oriented resource supply, collection, and recovery, and discover new stakeholders according to the new SCM
- Verify the applicability and effectiveness of developed SCM theories and system techniques corresponding to product types, service types, and B2B/B2C business model

(3) CE Product Planning and Digital Marketing

The aim is to research and develop a new theory for "CE product planning" that the target customer will purchase; to use the product, and to devise a "digital marketing" system technique for sales promotion of the product.

- As the new theory of "CE product planning", after conducting "persona analysis" to discover future target customers corresponding to CE-VCM, product service planning can be implemented in the following three steps: product structure and functional utility/benefits; utility and benefits from the perspective of customer use experience scene (TPO: time, place, occasion); and the customer's internal physiological, psychological and emotional utility benefits
- Using PLM (product lifecycle management) software when developing new system techniques for “CE product planning” and construct and maintain various BOM (bill of materials) databases that correspond to the series of processes of CE product planning, design, material procurement, manufacturing, sales, and maintenance services
- As a new system technique of "digital marketing", it is vital to grasp the preferences of individual customers based on the collection, accumulation, and analysis of usage experience data for individual customers. AI one-to-one marketing tactics should be tailored to each individual customer's preferences

(4) Smart Product and Service Lifecycle Design

The role of the product and service is to collect each customer's usage experience data from the aforementioned "CE product with IoT (Internet of Things) function " purchased and used by customers, and to deliver the collected data to the "CE shearing platform" described later via the internet. In addition, the platform analyzes the usage experience data and then sends one-to-one marketing tactical information using AI on the IoT product side to provide appropriate services to individual customers. For example, the smartphones used by many customers are an example of modern IoT smart products.

- The theory of “product and service lifecycle design” consists of the following design steps:

1) Determining the product service business model (product sales, rental/lease, shearing services, subscriptions, etc.)
2) Multi-generation flow of product and service lifecycle design compatible with CE-VCM
3) Product architecture design for individual products and services, and product strategy for multi-generational products such as product family design in relation to 2) above

- As the system technique for the product and services, the product architecture is detailed in the following three layers:

1) Top hierarchical level: basic overall design of the product or component, and service
2) Middle hierarchical level: control system, software system (OS, middleware, application software)
3) Lowest hierarchical level: components or mechanisms of various devices and interfaces between them

- Complementing the system technique of the smart product service mentioned above, the description method of "requirements definition" for each hierarchy level consists of the following five steps:

1) R (required specifications)
2) F (function)
3) L (logic)
4) S (structure)
5) V (testing and verification)

- To implement the aforementioned smart product and service system technology into a practical manner, the aforementioned PLM software will be used to create various BOM databases that correspond to the series of processes involved in "smart product and service life cycle design".

(5) Sharing Platform and Application Software Compatible with CE-VCM

The first important role of the "sharing platform compatible with CE-VCM" (hereafter referred to as "platform") is to quickly carry out mutual information transmission between the platform and application software, the product and service with IoT function, and customers via the internet. The second role is to accumulate and analyze each customer's usage experience data by utilizing the database and information processing functions in the platform. The third role is one-to-one marketing that responds to the preferences of each individual customer (referred to as "individual customer") while integrating with the digital marketing system techniques mentioned above based on the tactics provided by the analysis results.

Below are the design steps for the sharing platform and application software:

- Theory for the overall design of “sharing platform:” Define each customer service content to be appropriately provided to the individual customer corresponding to the flow of work steps included in the CE-VCM business process. Define which stakeholder involved in the CE-VCM business process should play a role in each customer service content. In addition, define what information should be exchanged among the platform, individual customer, or stakeholder when performing each work step.

- Theory for the overall design of "application software:" It is necessary to design and develop new "application software" that allows the individual customer to perform the proper actions they should execute in line with the flow of work steps operated by the platform. This application software can be operated within the " the smart product terminal with IoT function " purchased and used by the individual customer. An initial customer who wishes to use this platform must download this application software from the platform into his/her own smart product terminal and enter each individual customer's attribute information. As a result, when collecting, accumulating, and analyzing usage experience data, overall information processing within the platform and application software can link individual customer IDs (membership number IDs).
- System technique for required specifications: To design the "platform business structure" that follows the flow of the business process of the overall design above, the following methods, procedures, diagrams, and explanatory texts have created and utilized as a worksheet (WS): Business process model diagram WS, transaction information (commercial flow, physical distribution, information flow, money flow) regulation table WS, customer behavior process diagram WS, customer service processes WS corresponding to the customer behavior process, and overall definition document WS of required specifications for platform business structure that summarizes the contents of all the WSs mentioned above
- System technique for functional requirements: Create and utilize the following methods, procedures, charts, and explanations as the WS to design a "platform information communication system" that follows the flow of the aforementioned overall design business process: use case diagrams WS, data flow diagrams WS, timing charts WS, algorithms/flow charts WS
- Database management (DBM) system technique for the individual customer: While each individual customer (individual customer) uses the platform and application software, the customer experience data generated is collected, accumulated, and analyzed in the platform DBM. In order to design a DBM to provide one-to-one marketing tactics, create the following WS: Database structure design WS corresponding to the information processing algorithm above and interface requirements definition document WS between internal and external systems.

7.2 CE International Trend Surveys and Case Studies of Advanced CE Companies

The second purpose is to present how to proceed in international trend researches on CE policy and international standardization in each area and country (Japan, EU, USA), and in case studies regarding advanced CE companies in each industry.

(1) CE International Trend Surveys

The international trend surveys concerning CE policy and international standardization should be studied in each of the following four levels:
1) International standard (ISO, CE Technical Committee, ISO/TC323) level
2) Regional level (e.g., EU, North America, Asian regions)
3) Country level (e.g., the USA, Germany, Italy, Japan, etc.)
4) At the level of industry associations and unions and academic research trends by industry

(2) Research Approach for Case Studies of Advanced CE Companies by Each Industry

The case studies of advanced CE companies should be conducted according to the following steps in each industry:

Step1: Case studies of advanced CE companies focus on the following six industrial fields:

- Automobile
- Electronics and devices
- Construction
- Food and agriculture
- Chemical and materials
- Software and platforms

Step2: As indicated in **Table 5.1**, Japanese researchers and foreign researchers are responsible for determining the respective industrial fields.

Step3: Grasping the characteristics of CE management strategy among individual companies within the same industry. Furthermore, the characteristics of each other company's CE management strategy and management activities are compared from the following five research issues mentioned above:

- CE value chain management (CE-VCM)
- Recycling resource supply and resource recovery
- CE customer service and digital marketing
- Product and service lifecycle design
- Sharing Platform and application software

Step4: In terms of the differences in the features associated with the five research issues, comparative research on the characteristics of each company's CE management strategy and management activities within the same industrial field and between different countries (USA, Germany, Italy, and Japan).

Table 5.1 Research role sharing of case studies of advanced CE companies on six industrial fields

Industry Sector	**Researchers (Japan)**	**Researchers (Abroad)**
Research Supervisor	**Kin'ya Tamaki**	
1. Automobile	Park Youngwon / Khakimova Shakhnoza	Teresa Wu / Maitry Ronakhbai Trivedi (USA)
2. Electrical and Electronics	Hiroshi Yasuda, Yasutaka Kainuma	—
3. Construction	Yuko Kuma	Thomas Bock / Rongbo Hu (Germany), Simona Tondelli / Giulia Marzani (Italy), Fernanda Cruz Rios Ford (USA)
4. Food and Agriculture	Jiro Usugami	—
	Park Youngwon / Naomi Wakayama	
5. Chemical and Materials	Hiroshi Sakuta	—
6. Software and Platforms	Hiroyuki Kameda	—
	Yoshiki Nakamura	

8. Conclusion

Chapter 2 presented the CE definition and CE principles from the Ellen Mac Arthur Foundation (EMF): 1) designing in a manner that does not generate waste and pollution; 2) continue to use products and raw materials; and 3) regenerate natural systems. Based on the CE Principles, the EMF presented an "EC butterfly model" consisting of both the "biological cycle" and "technological cycle".

Chapter 3 described the "Cradle to Cradle certification (CRADLE TO CRADLE CERTIFIED®)" operated by the Environmental Protection Promotion Agency (EPEA). To receive the certification, five conditions must be met: 1) health of raw materials; 2) reuse of raw materials and parts; 3) use of natural energy and carbon management; 4) water stewardship; and 5) Social fairness.

Chapter 4 introduced CE policy trends in EU. The "Eco-design working plan (2016-2019)" was issued in 2016, with the purpose of identifying working commissions' priorities under eco-design and energy labelling. The first "circular economy action plan" was adopted in 2015 as part of previous initiatives promoted by the European Commission. The European Commission adopted the "New Circular Economy Action Plan" in March 2020. The key actions were listed under seven macro areas that correspond to seven overall goals and targets: a sustainable product policy framework; key product value chains; less waste more value; making the circular economy work for people, regions and cities; crosscutting actions; leading efforts at global level; and monitoring the progress.

In Chapter 5, the international standards (ISO)/TC (Technical Committee) 323 started to design the ISO 59000 series of CE documents to harmonize the understanding of the circular economy and to support its implementation and measurement: 1) ISO/CD 59004: Terminology, principles and guidance for implementation and CE international standards; 2) ISO/CD 59010: Guidance on the transition of business models and value networks; 3) ISO/CD 59020: Measuring and assessing circularity; 4) ISO/CD TR 59031: Performance-based approach – Analysis of cases studies; 5) ISO/CD TR 59032: Review of business model implementation; and 6) ISO/WD 59040; Product circularity data sheet.

Chapter 6 presents trend surveys regarding CE policy and industries case study in Japan. The Study Group on Circular Economy Vision at the Ministry of Economy, Trade and Industry (METI) compiled a report titled “Circular Economy Vision 2020.” The Japan Business Federation (Keidanren), in cooperation with METI and Ministry of Economy, established the “Japan Partnership for Circular Economy (J4CE)” on March 2021. They selected especially noteworthy cases and initiatives, and published brochures entitled “Noteworthy Cases” as 2021/2022 Edition.

Compared to the EC policy mentioned above, the responses to the CE trend in Japan, the Japanese government's CE policy, and the CE management strategy in the industrial world are considerably behind. In the future, when Japanese companies conduct global business transactions, it will be pivotal to be able to implement a CE management strategy compatible with the ISO 59000 series.

Chapter 7 presented the research framework of five new theories and system techniques for “development, empirical research and dissemination of and system techniques of the circular economy (CE) to meet the SDGs Goal 12: Producer and Consumer Responsibility" selected for the Grant-in-Aid for Scientific Research, Basic research (B), Japan:

1) Multi-generational and CE value chain management (CE-VCM)
2) Cyclical resource supply and resource collection
3) CE product planning and digital marketing
4) Product and service lifecycle design
5) Sharing platform and application software compatible with CE-VCM

The second research purpose was to present how to proceed international trend researches concerning international standardization, CE policy in each area and country (Japan, EU, USA), and case studies regardingof advanced CE companies in each industry.

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7.2 ISO/CD 59010 - Circular Economy — Guidance on the transition of business models and value networks: https://www.iso.org/standard/80649.html
7.3 ISO/CD 59020 - Circular Economy — Circular Economy — Measuring and assessing circularity: https://www.iso.org/standard/80650.html?browse=tc
7.4 ISO/CD TR 59031 - Circular economy – Performance-based approach – Analysis of cases studies: https://www.iso.org/standard/81183.html?browse=tc
7.5 ISO/CD TR 59032 - Circular economy – Review of business model implementation: https://www.iso.org/standard/83044.html?browse=tc
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Circular Economy in U.S. Automobile Industry: Literature Review and Case Study

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Abstract

Circular economy emerged in the 1970s with the idea centering around managing the enterprise design and operation to achieve the goals through efficient acquisition and utilization of resources. The fundamental concept of circular economy is based on the product's whole life cycle, from the design of products with an expected longer life cycle; to the creation of products with different uses at different periods of their life cycle; to recycling and reusing components to minimize waste; to the overall systematic approach to supply chain to assess the interconnections between materials, energy, and natural environments.

Currently, there is a lack of consensus on the definitions and terminologies of the circular economy. In the 1980s, concurrent engineering, and design for X, primarily focused on manufacturing, production and implementation of the circular economy. Later, supply network and green supply chain management, focusing on the organization's core competencies while outsourcing others to specialized supply network partners, are an implementation of the circular economy. It is observed that circular economy research these days moves more toward the endpoint of the product life cycle focusing on the 6Rs: reuse, recycle, redesign, remanufacture, reduce, and recover. With circular economy research evolving over the years, the goal remains the same - maintaining a sustainable and resilient environment. Of note, the challenges that organizations are facing are wide-ranging and include intense competition, global markets, global sourcing, global financing, global strategy, enhanced product variety, mass customization, service business, quality improvement, flexibility, advances in technology, and now added environmental issues. Therefore, an organization should develop a flexible knowledge supply chain to enable mass customization of environmental-benign products and environmental-conscious services, enable seamless integration of multiple, distinct business entities such as production facility, marketing, and post-sale service by using modern information technology.

The field of circular economy needs to continuously monitor its research base against evolving industrial realities. The core of circular economy, however, will continue to remain with the decisions of product design and management of the transformation processes that create value for organizations and society. Operations will still be a human organization which converts ideas for products into reality from raw and recycled materials. To this end, it is time to revisit circular economy and its evolution. In this research, we first search the literature on science direct (2000-2023), summarize the research findings, and present its implementation in the automobile industry in the USA using three case studies. By reviewing the literature from the past and present, we may have a plan for the future.

Keywords: Circular Economy, Concurrent Engineering, Supply Chain Management, End-of-Life Vehicles

1. Introduction:

Due to the increasing population and economic growth, the demand for raw materials is high. But there are limits to the supply of necessary raw resources. The extraction and utilization of raw resources substantially influence the ecosystem. Additionally, it increases energy use and CO_2 emissions. Therefore, it is essential to recycle the material to balance environmental conservation with economic growth (Zhu et al. 2010). The industry has been following the conventional linear economy for years. In a linear economy, materials are harvested, utilized, and ultimately disposed of with little to no effort made at reuse or recycling. With minimal consideration for the waste and resources created, a linear economy places the emphasis on creating new items and consuming as much as possible (Jørgensen et al. 2018). The major limitation of this "take-make-consume-dispose" model is that it is resource intensive and generates waste which leads to having a negative impact on the environment.

With the release of publications by economists Karl Polanyi (Barham et al. 1997) and Nicholas Georgescu-Roegen (Georgescu-Roegen et al. 1999) who highlighted the limits of growth and the significance of sustainable resource usage, the idea of a circular economy first emerged in the early 20th century. Later in the 1970s and 1980s, a Belgian economist named Walter R. Stahel popularized the phrase "circular economy". The key principle of the circular economy consists of 6Rs (*reuse*, *recycle*, *redesign*, *remanufacture*, *reduce,* and *recover*) (Wu et al. 2014, Jawahir et al. 2016). The official definition of circular economy was provided by the European Commission in 2015: "*The circular economy is a model of production and consumption, which includes the sharing, rental, reuse, repair, renovation, and recycling of existing materials and products as much as possible*." As a result, the product life cycle is extended. In practice, this means reducing waste to a minimum. When a product reaches the end of its life, its materials are kept in the economy where possible. These can be used productively over and over again, thus creating further value (Voulgaridis et al. 2022).

In contrast to the linear model, the circular economy is an economic model that prioritizes the reduction of waste and the conservation of resources. It functions in a closed loop where materials and resources are kept in use for as long as possible rather than the conventional linear model. Circular economy keeps products, materials, and components in use at their highest value at all times ultimately seeking to decouple economic growth and development. The primary difference between the traditional linear model and the circular model is that the linear model prioritizes profitability irrespective of the product life cycle whereas the circular model aims for sustainability. Both the models are explained graphically in Figure 1.

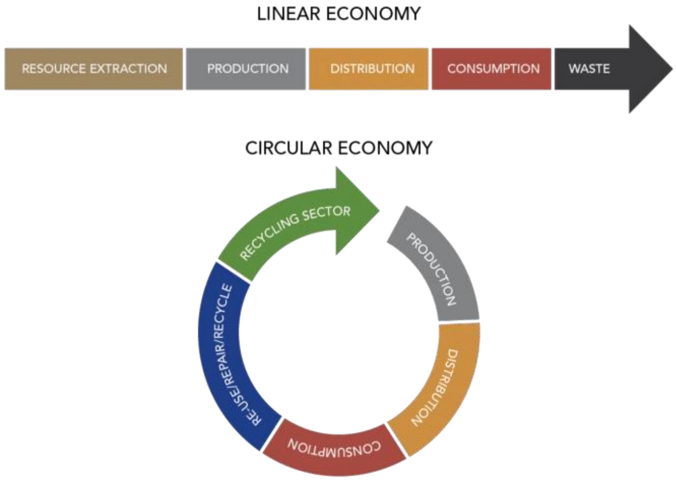

Figure 1: Linear vs Circular Economy (Unterfrauner et al. 2018)

By eliminating the linear trend, the circular model introduces the closed loop process where the notion of waste from the value chain is removed. The economy becomes less vulnerable to changes in material prices as a result of closed-loop operations, and the flattening of the cost curve ultimately leads to a more effective use of resources in terms of both value and volume (Sariatli et al. 2017). Moreover, utilizing the characteristics of circular economy throughout the research and development phase promotes the development of more efficient and durable components. Developing a more circular economy could have advantages including easing environmental stress, enhancing the security of the raw material supply, raising competitiveness, encouraging innovation, and accelerating economic growth.

One of the pioneers of circular economy, Ellen MacArthur Foundation has illustrated the flow of materials in circular economy using the butterfly diagram shown in Figure 2. It is a graphical depiction of the principles behind circular economy, a way of conducting business that aims to conserve resources and minimize waste. The "biological cycle" on the left and the "technological cycle" on the right are the two primary components of the diagram, which is divided into two main sections by a central axis that symbolizes the flow of materials.

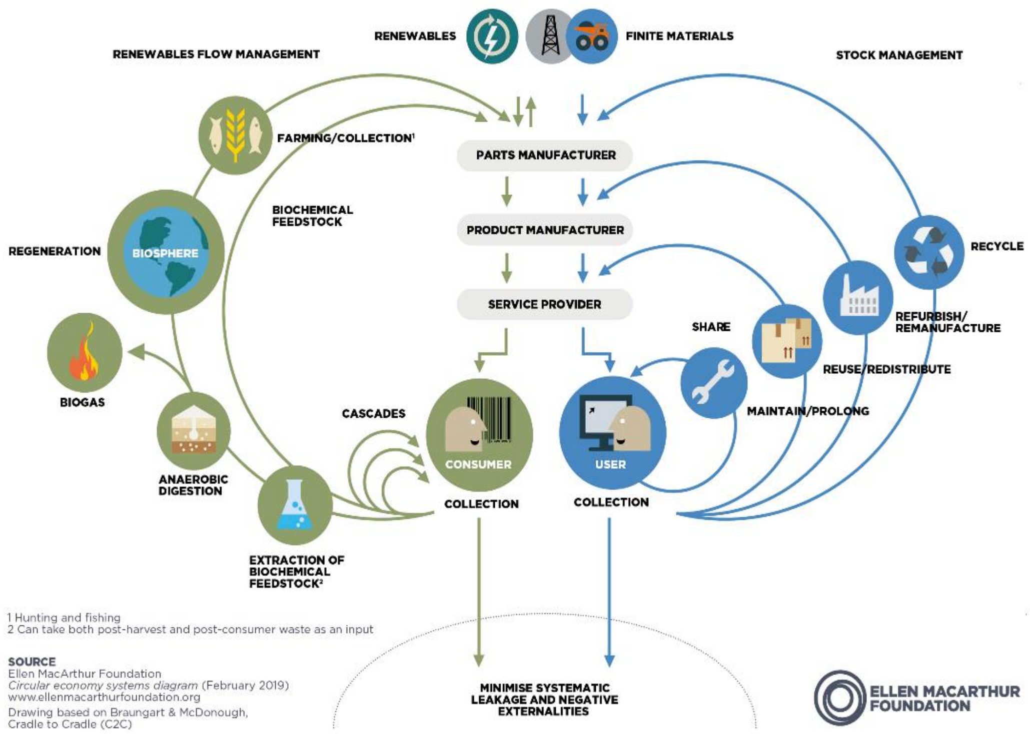

Figure 2: Butterfly Diagram (Elen Macarthur Foundation)

In the technical cycles, product components, and materials are kept in circulation in the economy as long as possible. This is mainly used for products made from non-biodegradable materials such as metals. The most effective technical cycles involve maintaining and reusing products. This leads to the preservation of the product value and increased usage length. For example, repairing a car or arranging a carpool in order to share the car between several people is less resource intensive than building an additional car. When there is no need for the product for a particular user, it might be reused by others by reselling or redistributing it to different markets. Once the product is no longer reusable, it can be refurbished or remanufactured. When none of the above is possible, the materials of the product can be recycled which will help in preserving the value of the material.

On the other hand, in biological cycles, the nutrients are restored to the biosphere while rebuilding natural capital. Biodegradable materials such as food or wood-based products can be cycled in biological cycles. Though these kinds of materials are biodegradable in nature, further value can be created by cascading them for additional applications in different value streams. In biorefinery, the conversion process can produce high-value chemicals and fuels. Organic materials that can't be used can be composted to extract valuable nutrients. By leveraging these recovery strategies, systemic leakages and negative externalities can be minimized. Ultimately, circular economy promotes getting the most value from the resources by keeping them at their highest utility and value.
The concept of circular economy is not new, however, as it evolves, the scope expands with initial engineering (e.g., concurrent engineering) focused initiative, to global supply chain, to now including

material science, and social science. Recognizing the strong momentum of circular economy and its practices in industries, we conduct a detailed literature review on the circular economy with a focus on the automobile industry in the USA. Specifically, we review the literature about the history of circular economy and comparison of modeling research for circular economy in Section 2. In Section 3, we present three automobile case studies: Ford, Daimler Trucks, and Caterpillar. The limitations and challenges of applying circular economy in various sectors are discussed in Section 4.

2. Literature Review

To review the existing literature on circular economy, we search the journal papers and articles on science direct databases (https://www.sciencedirect.com/) by using the following search terms that include relevant keywords: (circular economy OR concurrent engineering) AND (Automobile) AND (literature review OR case study). We consider the journal publications to range from 2000 to 2023. Figure 3 shows the publication year with the total number of publications indicating a strong uptrend in this research topic.

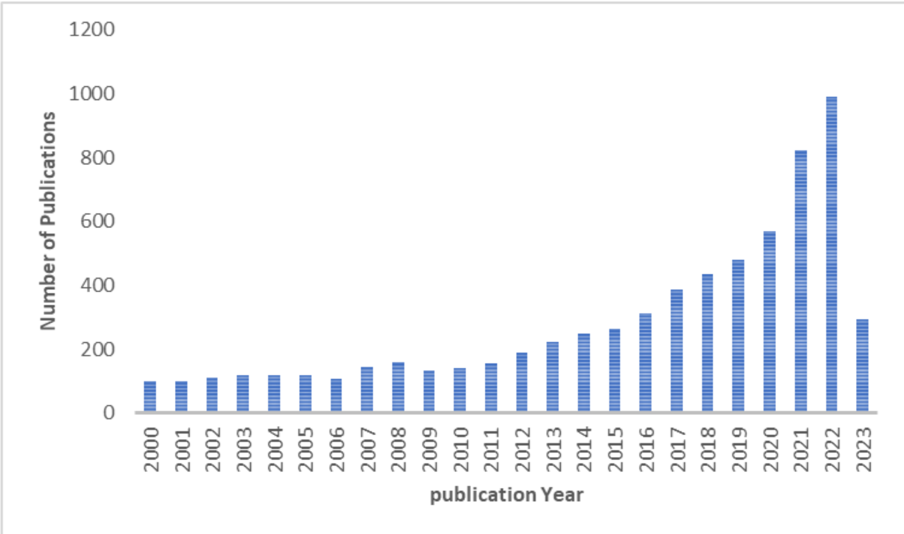

Figure 3: year vs the number of publications related to circular economy

Guided by a technological revolution, circular economy is progressively pushing manufacturers (e.g., automobiles) towards delivering increasingly complex solutions. The core of circular economy concept and its implementation is a decision: product design decision (e.g., material for better recyclability), supply chain decision (e.g, transportation logistics for better sustainability), marketing and policy decision (e.g., promoting reusability), just to name a few. In the following sections, we review research in the area in chronological order, from concurrent engineering (1990's), and supply chain management (2000's) to a circular economy (present).

2.1. Extending Concurrent Engineering for Circular Economy

As early as 1990, the emerging research from the engineering discipline implementing the circular economy concept is concurrent engineering (a.k.a. simultaneous engineering). Concurrent engineering has been defined in a number of ways. For example, O'Grady et al. (1991) defines concurrent engineering as the consideration, during the design phase of the factors associated with the life cycle of the product including manufacturing, assembly, testing, maintenance, reliability, cost, and quality. Keys et al. (1990) define concurrent engineering as the designing for the life cycle from the early product concept, the completed projected life of the product, including the product/market research, design phases, manufacturing process, qualification, reliability issues, and customer service/maintainability/supportability issues". Ziemke et al. (1991) consider concurrent engineering as a process in which a major new product or a significantly different new model of an existing product line is designed. Subramanyam et al. (1989) define concurrent engineering as an improved product development practice to reduce product development time and cost and to achieve high quality by concurrently integrating a wide spectrum of life-cycle concerns.

While there may be different definitions of concurrent engineering, there is general agreement that concurrent engineering is concerned with improving the product development process, by concentrating on the design stage. There is also general consensus that concurrent engineering, at least in its idealized form, is concerned with the whole *life cycle* of the product. The importance of the design process aspect of concurrent engineering is characterized by the cooperative design, production, distribution, and support divisions throughout the life of a product. In this regard, concurrent engineering can be seen as the design process performed under a larger number of constraints and more diverse design objectives than those of sequential engineering.

Based on the degree of creativity and cooperation, concurrent engineering techniques can be in general classified into six levels: the lowest degree of creativity and cooperation being network-based techniques, followed by documentation-based techniques, variable-driven techniques, predictive techniques, knowledge-based techniques, with agent-based techniques such as having the highest degree of creativity and cooperation. Design for X (DFX) is an effective approach to implementing concurrent engineering. Here X is assembly, manufacturing, power, cost, reliability, etc. An extension of the concurrent engineering approach to the circular economy is to extend X to 6Rs (Jawahir et al. 2016), specifically, *redesign* and *remanufacture* the product considering *reuse, recycle, reduce,* and *recover.*

2.2. Extending Supply Chain Management for Circular Economy

As research on concurrent engineering progresses, researchers recognize the trend of globalization thus supply chain management emerges. Supply chains are more complex and globally dispersed, requiring a more integrated and collaborative approach to their design and management. This could result in developing a more comprehensive and integrated approach to supply chain design that takes into account the entire system and helps organizations make better decisions to improve their overall performance.

Given that the operation of supply chains can be fraught with complexity, the level of complexity only increases when consideration of the design of products is taken into account. Yet there could be considerable benefits in designing supply chains taking into account both the operation of the supply chain and the design of the product with circular economy mindset. It is difficult to overestimate the importance of design decisions. For example, it has been reported that upwards of 70% of a product's manufacturing cost is dictated by decisions made during the product design stage. In the related area of including the effects of manufacturing in the design, the benefits are well documented in the literature and include a reduction in design changes, lower life-cycle costs, as well as shortened product development time. Furthermore, the relationship between shortened product development time and increased market share is strong. It is therefore to be expected that substantial benefits can result from joint consideration of the design of the operation of the supply chain and the design of the product to be produced by that supply chain. These improvements can include reduced product development time, reduced product cost, increased quality, and reduced product lead times.

While there is a considerable motivation for companies to implement a simultaneous consideration of supply chain design and product design, of similar importance is the consideration of the processes used to manufacture the product and reduce waste. Swink et al. (1999) define New Product Manufacturability (NPM) as an assessment of the degree of fit between the specifications of the design of the product and the capabilities of the production processes. Hence, the consideration of process design is directly linked to how the product is designed. Product design changes can affect decisions regarding how to manufacture the product as well as other factors such as quality, cost, lead time, recyclability, and waste associated with circular economy.

A key element in joint supply chain, product, and process design for circular economy is the development of a modeling approach that can represent the effects of product decisions (e.g., non-biodegradable materials) and process design decisions (e.g., energy/power consumption). Arora et al. (2000) state that it is difficult to understand complex systems and make changes to globally improve their performance without a model of the system. The use of such a modeling approach would give some insights into both the behavior of a sustainable supply chain and the implications of product and process design changes. This can be used as an aid for managers as the basis of improved decision-making.

There are a variety of modeling techniques that potentially could be used to model design and operation decisions. These approaches can be divided into two distinct categories: (1) optimization approaches; (2) pure modeling approaches. Optimization approaches include linear and integer programming as well as the variants of nonlinear programming. Perhaps the first paper to apply LP/IP/MILP (Linear Programming, Integer Programming, and Mixed-Integer Linear Programming respectively) model to the strategic design of a supply chain was the work of (Geoffrion et al. 1974). However, LP/IP/MILP approaches suffer from two main shortfalls. First, the size and complexity of a typical supply chain mean that LP/IP/MILP approaches can involve an overwhelming number of variables and constraints. Maintaining the model under such circumstances can be inordinately difficult, while the computational burden can be heavy. Second, the assumption of linearity may not hold. The option of using piece-wise linear approaches can add increasing complexity to the model. While nonlinear programming has been investigated for supply chain design, this approach involves significant complexity, with unwieldy models and extensive computation. In addition, nonlinear programming approaches may converge to non-optimal solutions.

Pure modeling approaches aim to model systems without the optimization elements of the approaches described above. Instead, they rely on managers, or other decision makers, to analyze the results and determine improvements to be made. Pure modeling approaches include simulation and network-based approaches. Simulation models can be very thorough but are extremely time consuming and costly to build and maintain and can become cumbersome in the level of detail needed to make the model work. Often, the time it takes to even collect the data to model the system can become cumbersome and this is compounded by the time it takes to input the data into the model. Additionally, creating simulation models requires skills that can often be lacking unless people have been specifically trained in the simulation environment. Therefore, simulation can be an expensive and time-consuming method for modeling a system. An alternative pure modeling approach is network-based approaches, based on Petri-Net models (Petri et al. 1962). Network-based approaches abstract the operation of a system to the flow of tokens through a network represented as a bipartite graph (Zurawski et al. 1994, David et al. 1994, Desrochers et al. 1995, Zhou et al. 1995). It is possible to set up state equations, algebraic equations, and other mathematical models governing the behavior of a system and thus model behaviors comprising concurrency, asynchronous events, synchronization, sequential operations, and resource sharing. Network-based approaches have a number of potential advantages as a modeling approach: they capture the precedence relations and structural interactions of stochastic, concurrent, and asynchronous events; they are logical models derived from the knowledge of how the system works and thus can be easily understood; conflicts and buffer issues can be modeled; deadlocks in the system can be detected; and they have a well-developed mathematical foundation that allows a qualitative and quantitative analysis of the system. Additionally, network-based approaches combine both a graphical and mathematical foundation to make not only a powerful analysis tool but an effective communication mechanism, as well. The graphical nature allows a self-documenting and visual representation of complex systems.

As environmental issues are becoming more and more restrictive for producers, some of the challenges facing companies in the supply chain, product, and process design decisions are using recyclable materials, recycling the final products, disposal of industrial waste, managing reverse logistics flows, green consumerism and green product development. From marketing and manufacturing to human resources and information technologies, almost all functions of an organization are under pressure to become environmentally sound. Managing reverse flows with recycling effectively using reverse engineering principles will have a clear impact not only on logistics but also on sales and marketing, and new product development.

While products become more globally focused, there is an increasing need to implement environmentally friendly policies along with the supply chain models. Management of green supply chains may be influenced by product life cycles, organizational value chains (including green purchasing/procurement, production, distribution, reverse logistics, and packaging), environmentally conscious business practices (such as leanness, re-usage, re-manufacturing, recycling, and disposal) and organizational performance measures. While standards like ISO 14000 may lead to more strict measures on environmental policies, total quality environmental management needs to be improved as an organizational goal. Thus, political and ethical concerns in terms of the production and sales of goods and services become an inevitable part of marketing strategies.

2.3. Review of circular economy practices in the automobile industry

As research from different disciplines (e.g., engineering, science, business) matures toward circular economy, industries follow the concept closely in their practices. For example, Aguilar et al. (2021) propose the circular economy framework for automobiles based on the Ellen MacArthur Foundation's principles (Ellen et al. 2017) and design a product life cycle. They have classified the stages of the vehicle life cycle as materials and manufacturing, use, and end-of-life. The materials and manufacturing phase consists of mining, extraction, refinement, transportation, and processing of raw materials into materials of a desired quality which will further be used to make the product parts. Hertwich et al. (2021) and Machado et al. (2018) discuss the consequences of replacing steel and iron with lightweight aluminum which will reduce the vehicle weight by 11 to 25% resulting in improved fuel efficiency and reduced emissions. Kamble et al. (2021) propose a Large Group Decision Making technique to integrate big data and circular economy practices in order to prioritize policy proposals for implementing circular economy practices in manufacturing organizations. In the core industrial and natural resource sectors that provide the raw materials for photovoltaics, wind turbines, electric cars, and lithium-ion batteries, Mulvaney et al. (2021) emphasize research on advancements toward a circular economy. They aim to draw attention to the steps that may be taken to implement low-impact extraction, zero waste, circular economy policies, and practices, as well as areas that require more research and collaboration in order to advance circular economy and sustainability goals. Martins et al. (2021) suggest a "Circular Car" development model throughout the product life cycle. They have suggested a list of circular practices which includes the development of alternatives to internal combustion engines, the development of circular materials, product design for dismantling and recycling, integration of reverse logistics into operations, and product-as-a-service: car sharing.

With the development of shared-use mobility platforms and transportation-as-a-service business models, the requirement for product longevity becomes even more critical (Nyström et al. 2019).

Therefore, product design plays a crucial role in promoting circular economy for automobiles. For example, designing cars that are built to last and can be easily maintained, repaired, and upgraded helps extend their lifespan. Mossali et al. (2020) propose a circular-economy-oriented redesign study for e-mobility batteries used for electric vehicles. According to the study, private conventional electric vehicles have fewer adverse environmental effects than shared autonomous vehicles. Circular economy practices are expected to reduce the global warming potential, water footprint, and energy demands of shared autonomous vehicles by 21.4 %, 18.2 %, and 17.3 % respectively. Anair et al. (2020) combine the concepts of Green Lean and circular economy demonstrates the implementation of a circular economy in the process of optimizing the production operation of manufacturing enterprises.

Ali et al. (2019) have introduced an innovative approach for reusing the sheet metal scrap generated from the car-body manufacturing process in the automobile industry and creating new material for the building exterior. This led to a reduction of approximately 40% (400 $/ton) and savings of approximately 67% (10 MJ/kg) of energy consumption. Ahmed et al. (2023) investigate how various circular economy strategies and energy mixes affect the environmental implications of shared autonomous electric vehicles. Mobility companies can enhance sustainability by providing ridesharing and on-demand mobility services compared to personal vehicle ownership. While some studies suggest that solo ride-sourcing may increase traffic and greenhouse gas emissions due to the idle miles driven to pick up passengers, shared mobility platforms may nevertheless produce less greenhouse gas emissions per passenger (Anair et al. 2020).

When adopting efficient circular economy solutions in accordance with current industry standards like quality and environmental management systems, it is necessary that industrial organizations improve their management systems. However, due to the lack of standardized, appropriate, and user-friendly supporting analytical tools, it is not yet a common practice. (Urain et al. 2020) have prepared an Industrial Circular Economy Questionnaire (ICEQ) which is a self-diagnosis questionnaire for business-level circular economy assessment. ICEQ was applied to 30 companies including various sectors like automotive, machining and metalworking transformation, waste management, machine tool, etc. They conclude that the automobile sector outstands the other sectors in terms of being conscious about applying circular economy as they must comply with end-of-lifecycle vehicles legislation.

The main hurdle for applying circular economy in the industry is that there are no specific guidelines to the sectors on how to implement circular economy and there is no internationally recognized standards institution to regulate the sector (Circular Academy et al. 2017). The effect of institutional factors, contextual factors, and strategic factors on the adoption of circular economy within service organizations and their impact on sustainable service provision is examined in the study (Erdiaw et al. 2023). The main findings of the paper state that the adoption of a circular economy is favorably correlated with organizational characteristics as well as sustainable service provision.

In summary, we review the research trends and emerging practices in circular economy in this section. In the following section, we present a case study in the U.S.A. automobile industry.

3. Case Study

In this research, our particular interest is to analyze the circular economy implementation in the automobile industry in the U.S.A. The rate of automobile ownership has been increasing at a higher rate than the global population (Sakai et al. 2014). As of 2022, there are about 1.446 billion vehicles on the earth and the United States contributes to 19% of this. Automobile parts contain valuable materials, such as steel, aluminum, and plastic, that can be recycled and reused. This conserves finite resources and reduces the demand for new raw materials. Automobiles include toxic substances like lead, mercury, and cadmium that, if improperly handled, can harm the environment. The amount of these dangerous substances released into the environment can be decreased by recycling and reusing automotive components. With the noticeable increase in the number of automobiles, there has been a significant increase in the generation of End-Of-Life Vehicles (ELV). ELVs are automobiles, trucks, or other types of vehicles that have outlived their useful lives or are no longer safe to drive on public roads because of aging, wear, and tear, or other circumstances. These cars are often disposed of at the end of their useful lives in an environmentally friendly manner, either by recycling or scrapping.

In addition to personalized automobile vehicles, around 22.8 million vehicles which cover everything including heavy-duty pickups and vans to transit and school buses, freight and work trucks, and tractor-trailers, travel more than 430 billion miles annually and use more than 55 billion gallons of gas (Lowell et al. 2021). Each year, the lifespan of 1 million HDOR vehicles comes to an end (Weiland et al. 2014). Medium and Heavy-duty trucks contribute to 60% of the f tailpipe nitrogen oxide (NOx) and particulate (PM) emissions while making up less than 10% of all vehicles on the road. As a result, the urban areas experience poor air quality. By reducing urban air pollution, the adoption of zero-emission automobiles and more renewable energy sources will have a substantial positive impact on public health. According to a recent study (Environmental Defense Fund, 2021), reducing tailpipe emissions from new medium- and heavy-duty vehicles by 2040 could result in up to $485 billion in health and environmental benefits.

Both automobiles and heavy-duty and off-road (HDOR) vehicles make a significant market share. The HDOR is further classified into namely heavy-duty vehicles (HDVs) mainly trucks, and non-road mobile machinery (NRMM), mainly agricultural and construction machinery. Therefore, we have reviewed three companies referring to each of the categories in this section. The definitions and examples of both automobile and HDOR vehicles are summarized in Table 1.

Table 1: Definitions and features of automotive and HDOR sectors (Saidani et al. 2018)

Categories Characteristics	Automotive Sector	Heavy-Duty and Off-Road (HDOR) Sector	
Sub-categories	Light Vehicles	Heavy Duty Vehicles	Non-Road Mobile Machinery
Definition	Road vehicles weighing less than 3,5 tons	Nominally defined as vehicles weighing more than 3.5 metric tons	Mobile machine that is not intended for carrying passengers or goods on the road, and installed with a combustion engine
Examples	Passenger Cars & Commercial-light vehicles.	Trucks, Buses	Tractors, Excavators.
Applications, markets, usage	Mainly private individuals for daily use.	Mainly used for commercial purposes, notably in the freight moving	Agriculture, construction, mining and forestry

3.1. Case Study I - Ford

To reduce waste and encourage a more circular economy, Ford employs sustainable materials in its cars like soy-based foam, recycled plastic bottles, and natural textiles.

Ford creates its vehicles with easy disassembly, remanufacturing, and recycling in mind. Methods like modular design and clear labeling on parts are used to achieve this. It has also developed a number of waste reduction initiatives in its production operations, including lowering energy and water usage and adopting 3D printing to cut waste and boost productivity. It uses a closed-loop manufacturing system, which recirculates and reuses materials within the production process. For example, Aluminum scrap used to stamp truck bodies is returned to suppliers for creating new sheets. Moreover, Ford has collaborated with HP, together found a way to extend the life of the used 3D printed powders and parts by turning them into auto components for Super Duty F-250 trucks and creating a closed loop on waste. The new materials are 10% less expensive, 7% lighter, and have superior chemical and moisture resistance than traditional ones (Ford article).

Ford has decreased its global operational energy use by 30% since 2000 (3% better than a year ago), emissions by 39% (11% better than a year ago), and water use by 43% (21% improvement from a year ago). Ford reduced energy use in the US by 4.5%, saving the country around $18 million.

The circular economy applied at Ford is shown in Figure 4.

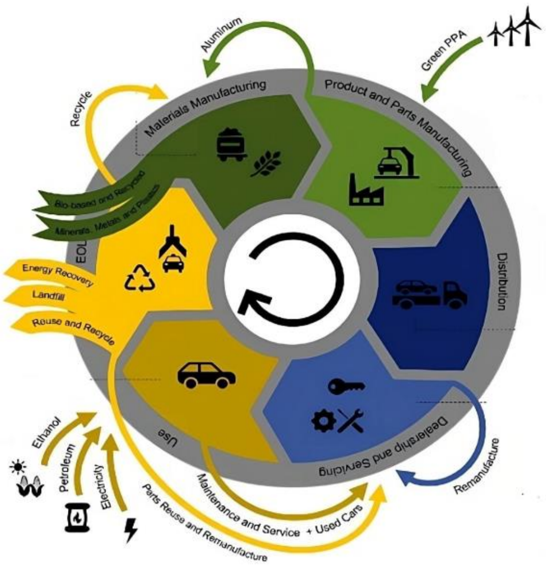

Figure 4: Circular Economy at Ford (Aguilar et al. 2021)

3.2. Case Study II – Daimler Trucks

Daimler Trucks is a North America-based company that has a "Green Freight" program that includes initiatives such as eco-driving training, alternative fuel vehicle development, and remanufacturing programs for components. Daimler Trucks has a remanufacturing program that refurbishes components from used vehicles, such as engines and transmissions, to extend their useful life and reduce waste. The program uses state-of-the-art technology to disassemble, clean, and rebuild components to meet original equipment specifications, and can help reduce the environmental impact of vehicle manufacturing. It is also developing a range of alternative fuel vehicles, including electric and hydrogen fuel cell models, to reduce emissions and dependence on fossil fuels. The company has also introduced natural gas and hybrid-electric vehicles to the market, which offer lower emissions and improved fuel efficiency.

Daimler Trucks received a “LEED Platinum certification” from the U.S. Green Building Council which requires a focus on energy efficiency, water conservation, indoor occupant health, and overall green construction. Over a period of 10 years from 2004 to 2014, Daimler Trucks reduced the energy usage at the Detroit manufacturing plant by 32.49% alongside a 93% increase in production (Daimler

Truck Article). The packaging and logistic team have been working on reducing the use of expendable packaging and the distance parts travel to our production plants since 2014 at Daimler. This has led Daimler Trucks to decrease waste by over 610,000 cardboard boxes and 230,000 wooden pallets per year, and it helped reduce annual emissions of CO_2 by over 18 million pounds. With the goal of "Zero Waste Landfill", Daimler Trucks has not just reduced the waste but also completely eliminated sending any waste to the landfill from any of its manufacturing plants. According to the report, Daimler Trucks has saved 4000 gallons of fuel per truck and 45 tons of CO_2 per truck. The Environmental Protection Agency (EPA) has worked to minimize commercial vehicle emissions throughout time, and between 1988 and 2010, the allowed emissions of particulate matter and nitrogen oxides were lowered by 98%. Currently, Daimler Trucks is exploring new business models, such as truck sharing and leasing, to optimize resource utilization and reduce waste.

To conclude, through various techniques and policies like fuel efficiency and emissions reduction, using sustainable materials, recycling, and remanufacturing, Daimler Trucks is working to create a more sustainable and efficient trucking industry.

3.3. Case Study III – Caterpillar

Caterpillar produces a range of construction and mining equipment such as bulldozers, excavators, and dump trucks. Caterpillar being a pioneer in remanufacturing technology and procedures restores things to like-new condition after they have reached the end of their useful life. This reduces ownership and operation costs by giving customers a brand-new quality for a small portion of the price of a new part. Although the circular economy is one of the more recent keywords in sustainability, Caterpillar has been implementing the idea for years. Initially, around 1973 a significant client of Caterpillar's engines for on-highway vehicles contacted the company in search of a repair alternative that was more time- and cost-efficient than buying new diesel engines. In the process of resolving the customer's request, Caterpillar discovered a business potential in remanufacturing, which was not well-known globally but might be profitable for the company because it was innovative and appealing to consumers in both a financial and practical sense.

Caterpillar purchases used Caterpillar construction equipment and restore them using recycled raw materials for 80% of the total, and further provides a guarantee of 90% efficiency. With a cheaper price, a new guarantee, and a new serial number, these machines are released onto the market. A comprehensive Cat Certified Rebuild program entails the replacement of almost 7.000 spare parts and more than 350 tests and inspections.

Around 2.2 million end-of-lifecycle units were returned to Caterpillar's remanufacturing program each year, which equates to (1) 73,000 tons of materials, including 50,000 tons of iron, and (2) 6000 distinct remanufactured goods, including engines, fuel systems, and tires. Large amounts of parts are returned to Caterpillar due to incentives including a deposit program and voluntary product take-back (Saidani et al. 2018). According to Jennifer Leustek, Product Manager working at Caterpillar, the company has taken 127 million pounds of material out of the marketplace and brought it back through the remanufacturing facilities. As compared to the manufacture of new parts, the caterpillar's remanufacturing process emits 1% less greenhouse gas emissions, uses 85% less water, consumes 85% less energy, and uses 85% fewer raw materials. Figure 5 illustrates the circular economy initiative implemented by Caterpillar.

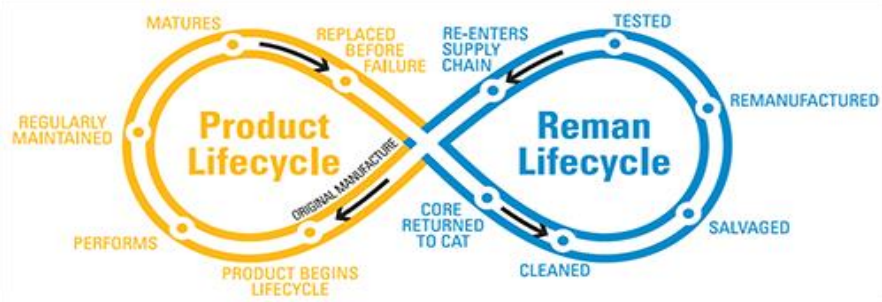

Figure 5: Caterpillar's REMAN value chain to close the loop (Snodgress et al. 2012)

4. Conclusion

In this study, we have reviewed the literature about how circular economy was introduced, what is its significance over the traditional linear model, and to what extent it is implemented in the automobile industry, particularly in the USA. We have also presented three case studies about applying circular economy in various sectors like automobile and heavy-duty vehicles. Although circular economy is a trending approach in the industry, there are some challenges and limitations of circular economy which needs attention in order to fully incorporate circular economy on a global scale. There is not enough literature about presenting various models for applying circular economy in the industry. Implementing circularity on a large scale can be difficult due to the complexity of supply chains and the need for coordination among various stakeholders. Implementing circular economy practices often involves significant changes to supply chains, which can be complex and challenging to manage. For example, products may need to be redesigned to be more easily disassembled and reused, and new partnerships and collaborations may need to be developed to ensure that materials and products are reused and recycled effectively. Overall, the circular economy faces several challenges and limitations, but these can be addressed through innovation, collaboration, and policy support to create a more sustainable and resilient economy.

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Circular Economy: Japanese Car Companies Experience and Current Status

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Abstract.
Circular economy has evolved over time and has been adopted by some organizations and sectors in their activities and operations. As a sustainable model, the CE could be applied to any sector of the economy. End-of-life vehicle (ELV) management is becoming increasingly important as the automotive industry is one of the world's most critical sectors and is rapidly expanding around the world. Some countries have already developed efficient recycling and recovery system in their car industry. For instance, Japan has formed a relatively well-round legal system, which guides the owners to deliver their vehicles with recycling fees. On top of that, Japan has formulated the ASR recycling target to guide the improvement of the vehicle recycling rate. With the market-oriented development of the industry, Japan has been confronted with the challenge of balancing policy designs and market demands. The goal of this study is to first investigate the ELV management systems in Japan, particularly in automobile industry, as well as to provide an overview of best practices in ELV management systems in selected three famous Japanese car companies like Toyota Motor Corporation, Honda and Nissan Motor Corporation. This review covered the current situation and progress of circular economy development from the perspective of the policy and the recycling practices of automobile companies in Japan.

Keywords: Circular economy (CE), automobile industry, End-of-life vehicle (ELV), ELV management.

1. Introduction

With economic development and accelerated industrialization, resource consumption has increased rapidly. Along with this consumer boom, vehicle ownership has rocketed up, which also has brought surging numbers of end-of-life vehicles. Thus, recycling and disposing those end-of-life vehicles (ELVs) turned out to be a head-scratching issue. The management of end-of-life vehicle (ELVs) and the appropriate treatment of the recycling residues has become the subject of worldwide concern [1]. For Japan the recycling and disposing end-of-life vehicles is not new issue and Japan is a pioneer in this field. As great achievements have been done in terms of circular economy, particularly in automotive industry. Therefore, there are many goals and strategies under the circular economy policy context that should be achieved in the nearest future because Japan with more population and less land, land resource is very scarce, and the available capacity of landfill sites for automotive shredder residue

(ASR) is becoming fewer and fewer. Moreover, the management of ELV recycling within a legal framework is becoming increasingly important, especially in reducing the negative impact of ELVs on the natural ecology as well as significantly contributing to efficient resource utilization and economic development. ELV recycling legislation initiatives exist in Japan [2]. For example, under Japan's End-of-Life Vehicle (ELV) Recycling Law which entered into force in January 2005, automobile manufacturers and importers are responsible for recovery, recycling and appropriate disposal with respect to fluorocarbons, airbags, and automobile shredder residue (ASR). Compliance with the law was anticipated to enable ASR to be recycled at a rate of 70% by 2015, resulting in an automobile recycling rate, by vehicle weight, of 95% (as compared with the 80% rate prevailing prior to the introduction of the law); those rates were in fact surpassed in 2008. Japan's vehicle recycling infrastructure as mandated by its ELV Recycling Law is the first in the world to administer the entire process of auto recycling—from ELV recovery to final disposal—on the basis of electronic "manifests".

2. Regulatory background of ELV management

So, what are the policy issues facing Japan, and how is the circular economy dealt with in a Japanese policy context? Japan's management on the automobile recycling industry have focused on waste disposal and recycling. In Japan, the Basic Environment Act was enacted in 1993 to define the fundamental principles and set the first policies on environmental protection, followed by the Basic Act on Establishing a Sound Material-Cycle Society in 2000 [3]. This Act focuses on the promotion and implementation of the 3Rs, reduce, reuse and recycle, proper waste management and a reduction in environmental impact [5]. It is grounded in the Waste Management Act, which importantly differentiated between municipal and industrial waste, and the Effective Resource Utilization Promotion Act, which are the main legislative acts for waste management and recycling, respectively. Furthermore, these are supported by automobile recycling act, green purchasing law and End-of-Life Vehicle Recycling law [6]. On top of the abovementioned laws and regulations, Japan has implemented such laws as Waste Disposal Law, Fluorocarbons Recovery and Destruction Law, and Law for the Promotion of Effective Utilization of Resources, regarding the automobile industry. However, it is the End-of-Life Vehicle Recycling Act that makes all the difference [7], which was officially put into effect on January 1, 2005. And the root cause of establishment this law was "Teshima incident". In the past there was a serious incident in Japan, after which many manufacturers changed their development vision and strategy. It was "Teshima Incident". 50 years ago, Teshima was considered Japan's "Garbage Island". About 29 hectares of land used to be the dumping ground of illegal industrial waste. The exposure of crimes on Teshima shook the nation and greatly influenced the revision of Japan's Waste Management [8]. To solve these problems with the dumping the government adopted the Law on Recycling of End-of-Life Vehicles in 2002, soon that year Automobile Recycling Act was enacted and started in 2005 that pushed all car companies to revise their policies regarding to recycling issues. The law is the one that was specifically enacted for automobile scrapping and recycling the disposals. After End-of- Life Vehicle Recycling Act has been put into effect, a new

ELV recycling system have been established, bringing Japan's automobile collecting, dismantling and recycling industry into a new development stage.

2.1. Organizations.

In Japan recycling and recovery systems are highly centralized, controlled and regulated by the government and government organizations, and supported by many companies and corporate associations.

At the governmental level there are two ministries that regulate the recycling system in Japan, they are Ministry of Economy, Trade and Industry of Japan (METI) and Ministry of Environment of Japan (MOE). These ministries have been promoting the "3R" policy in order to shift the society of mass-production, consumption, disposal to a sustainable economic system.

Besides this, some government associations and corporate organizations are involved to support the circular economy by introducing their strategies and initiatives.

JARC, the Japan Automobile Recycling Promotion Center, is a foundation created in year 2000 jointly by various automotive industry organizations led by the association of vehicle manufacturers, with a mission to advance the recycling of end of life vehicles (ELVs).

The Automobile Recycling Law was implemented in 2005 to revive Japan's automotive recycling system mainly by obligating the vehicle owners to pay a recycling fee in advance and by demanding the auto makers, dealers, dismantlers and other stakeholders to play their respective roles in the nationwide recycling system. JARC's major responsibility is to manage the recycling fees deposited by vehicle owners and to monitor the flow of ELVs in the automotive recycling system in order to make sure that all the players are doing their work.

About 80 percent of the weight of each ELV has been recycled in the form of reusable parts or reprocessed materials. On the strength of its state of the art expertise, JARC strives to play the leading role in raising the recycling rate higher to 95 percent or more [9].

Japan Automobile Recycling Cooperation Organization, as a partner in the recycling society, the Japan Automobile Recycling Cooperation Organization serves as a window for the smooth recycling of automobile fluorocarbons and airbags, helping to protect the global environment and promote a recycling-oriented society.

According to the Law Concerning Recycling of End-of-life Vehicles [4], which came into effect on January 1, 2005, domestic automobile manufacturers and automobile importers are required to recycle the three commodities designated by the law, chlorofluorocarbons for car air conditioners, etc. , gas generators for airbags, and shredder dust (automobile shredder residue) must be collected and recycled (appropriately treated). Twelve manufacturers and the Automobile Importers Association established this corporation in January 2004 as a single point of contact in order to properly, reliably and efficiently collect and recycle fluorocarbons and airbags among these items [10].

Japan Automobile Manufacturers Association, Inc. (JAMA) established in 1967, is a non-profit industry association which comprises Japan's fourteen manufacturers of passenger cars, trucks, buses and motorcycles. Its organization today is the result of the merger of the Japan Motor Industrial Federation (JMIF) and the Japan Automobile Industry Employers' Association (JAIEA) with JAMA

in May, 2002.
Automobile manufacturing integrates many supporting industries, and automobile use is the focus of a wide range of related industries. Directly or indirectly, roughly 8% of Japan's working population is involved in auto industry-related work. Auto production furthermore accounts for 18% of the total value of Japan's manufacturing shipments and for 40% of the value of the machinery industries' combined shipments. The automotive industry is thus one of the Japanese economy's core industrial sectors. The globalization of auto manufacturing also contributes significantly to local and national economies round the world.

JAMA works to support the sound development of Japan's automobile industry and to contribute to social and economic welfare. As directions in auto manufacturing increasingly influence the world we live in, JAMA takes its role and mission ever more seriously, on the road to sustainable mobility [11].

Japan Environment Association, Eco Mark Office: Introduction of the Eco Mark Program. The Eco Mark program which the Japan Environment Association undertakes, is managed in accordance with the standard and principle (ISO 14020 - An environmental label and declaration, a general principle, ISO 14024 - An environmental label and declaration, a type I environmental-label display, a principle and procedure) of International Organization of Standardization (ISO). This system is to be said that the use of the label is accepted by the organization of the third party based on independent and multi standards. In Eco Mark, the product category set as the object of Eco Mark is selected to the category of the products accepted to be suitable for environmental preservation in Eco Mark Committee for Establishing Category and Criteria which consists of the representatives, such as the industrial world, consumers and scholars. Certification Criteria for every product category has taken the environment the life stage (resource extraction, manufacture, distribution, use, disposal, recycling) of products into consideration and enacted [12].

At third level there are individual car companies and manufacturers that support at each stage of their performance Circular economy policy. As our goal of this paper to investigate the best practices and models of 3R Concept of Japanese automobile companies, in the next sections we deeply study them separately and observe their experience within the recycling and disposing systems.

3. Business model examples

In general, the Japan’s car manufacturers have acquired many achievements. Based on the principle of the “3Rs (Reduce, Reuse, and Recycle)”, aimed at further raising the recovery rates of End-of-Life Vehicles, many Japanese automakers maintain partnerships with outside operators to maximize the recycling of reusable materials and the reduction of waste. Some automakers in Japan participate in research with recyclers to optimize the dismantling of vehicles.

We observe the experience related to recycling of some Japanese car companies like Toyota, Honda, Nissan. It is important to analyze their strategies and achievements in the field of circular economy, by which we will be able to see and evaluate the current situation of the automobile industry in terms of sustainable development.

All of these companies have their own way to support the sustainable development and green performance. The next table shows Japanese car company's policies and strategies according to Circular Economy.

Table 1. Japanese Car Companies' Circular Economy Policies

	Toyota Motor Corporation	Honda	Nissan Motor Corporation
Existence of circular economy policy	Toyota Recycle Vision (2003-2015) Toyota Environmental Challenge 2050 (2015)	2030 Vision - Serve people worldwide with the "joy of expanding their life's potential" (2018), Triple Zero Concept (2011)	Ambition 2030 - Driving innovation to enrich peoples' lives (2021), Nissan's Circular Economy Concept

They are engaged to the development of recycling technologies, which contribute to the reduction of waste. For example, by Nissan waste generated globally in 2021 amounted to 158,199 tons, an increase from 153,160 tons in 2020. But by the treatment method 150,991 tons were recycled and 7,208 tons waste for disposal.

Table 2. Waste from the production [13]

	Unit	2017	2018	2019	2020	2021
Total	ton	152,674	206,645	199,470	153,160	158,199
By region						
Japan	ton	61,327	69,829	63,294	48,921	52,386
North America	ton	35,177	64,514	58,970	48,043	51,062
Europe	ton	45,268	49,662	50,205	31,868	33,895
Other	ton	10,903	22,639	27,001	24,328	20,857
By treatment method						
Waste for disposal	ton	8,041	7,231	6,365	6,539	7,208
Recycled	ton	144,633	199,414	193,105	146,621	150,991

In Japan, over the years since the enactment of End-of-Life Vehicle Recycling Act (MOEJ) in 2005, the ELVs recycling system has evolved into a new stage under the government regulations and market requirement that we reviewed before. By this table we can analyze that last years starting 2015 all car companies have achieved the high Recycling Rate about 95-96 %. And it is a big achievement. Below we observe each company's performance within circular economy separately.

3.1 Toyota Motor Corporation.

Toyota has been developing systems in response to the Law on Recycling of End-of-Life Vehicles

(2002). In order to strengthen activities to recycle end-of-life vehicles, Toyota adopted the Toyota Recycle Vision, which set long-term goals from 2003 to 2015. The Recycle Vision was aimed at realizing as soon as possible the 95% vehicle recovery rate to be achieved by 2015 (70% ASR recovery rate) [14].

Based on the realization that all resources are limited, Toyota has promoted effective use of resources such as measures to improve yield ratios and reduce the volume of packaging materials at the production stage, and taken various initiatives on recycling.

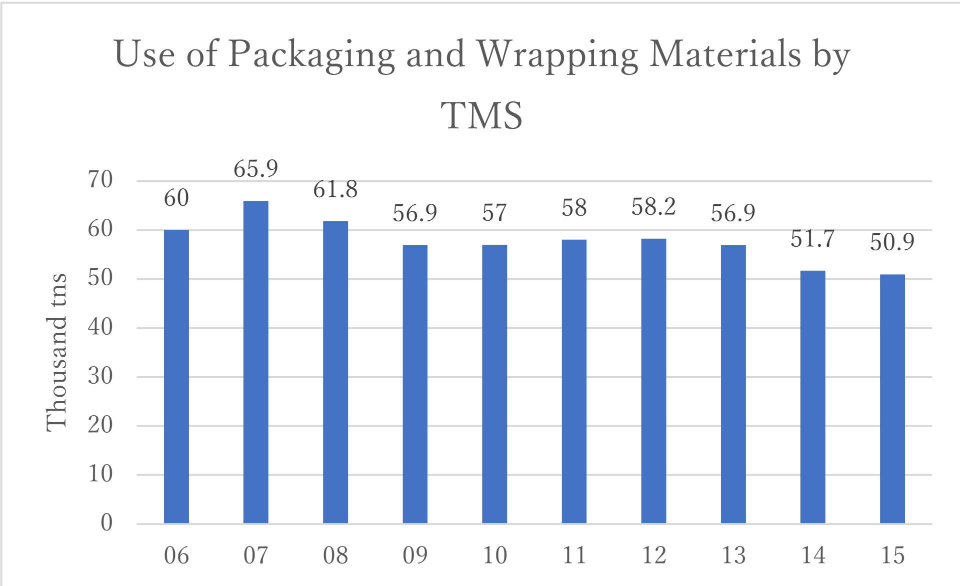


Figure 1. Use of Packaging and Wrapping Materials by TMC
(Data collected by the author from reports of Toyota company)

In order to reduce the use of packaging and wrapping materials, Toyota implemented measures that included simplifying wrapping specifications and expanding the use of returnable shipping containers.

Table 3. Result of Activities to Reduce Usage of Packaging and Wrapping Material
(Data collected by the author from reports of Toyota company)

Improvement	Products	Main details of activity	Reduction volume (thousand tons/year)					
			2010	2011	2012	2013	2014	2015
Simplification of specifications	Service parts	Changing packaging specifications, reuse etc.	5	0,9	1,6	0,8	0,7	0,1
		Increasing lean specifications for wrapping	1,3	0,2	0,3	0,2	0,1	0,3
	Production parts	Improvement of parts quantity per box, simplification of packaging specifications	0,5	0,5	0,1	0,1	0,2	0,3
Use of returnable containers	Service parts	Expanding the use of returnable containers	0,5	0,4	0,3	0,5	0,1	0,5
	Production parts	Expanding the use of returnable containers	0,5	0,2	0,3		0,2	0,03
Total			7,8	2,2	2,6	1,6	1,3	1,2

3.1.1 Reducing water consumption

TMC supported activities to reduce water consumption, for example, reducing steam usage in production processes. As a result of initiatives including promotion of water recycling particularly in regions with scarce water resources, there was decrease of 2.9 percent from 2013, (Figure 2).

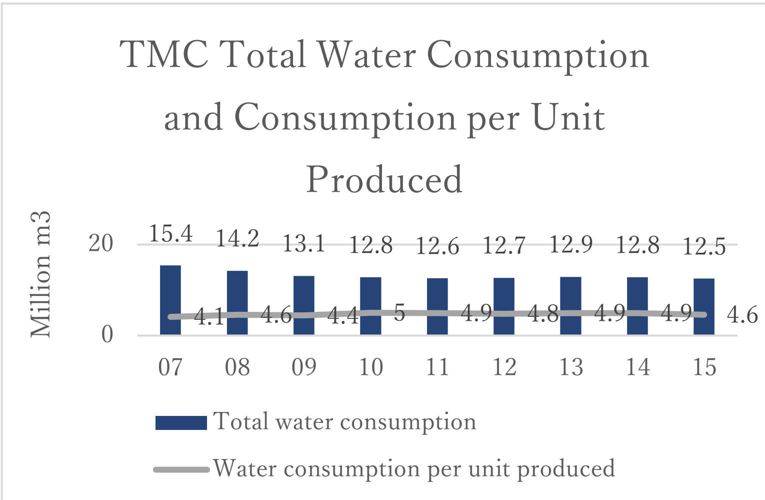


Figure 2. TMC Total Water Consumption and Consumption per Unit Produced
(Data collected by the author from reports of Toyota company)

3.1.2 Reducing waste volume

Toyota Motor Corporation continued implementing waste reduction measures such as reducing industrial dust and sludge volume. The total waste volume was 35.200 tons (a decrease of 2,0 percent from 2014), and the waste volume per unit produced was 12.5 kg (a decrease of 0,1 percent from 2014) (Figure 3).

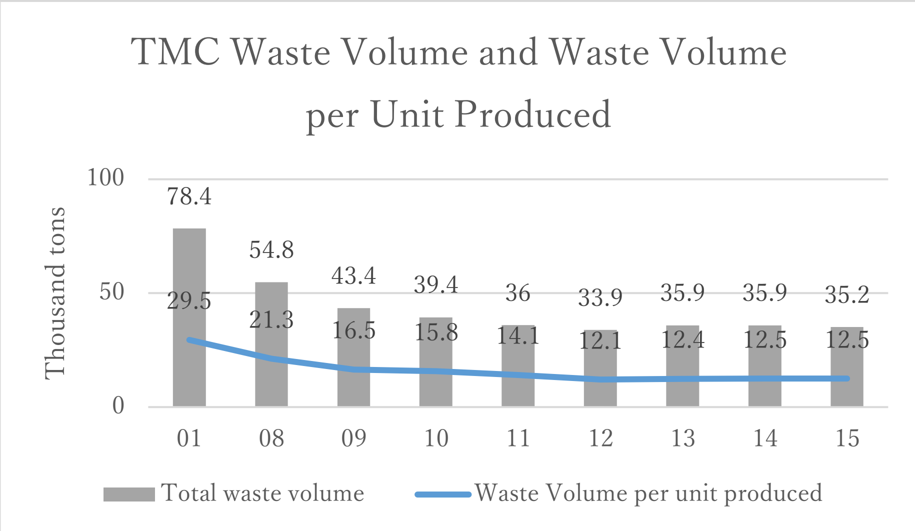


Figure 3. TMC Waste Volume and Waste Volume per Unit Produced
(Data collected by the author from reports of Toyota company)

3.1.3 Recycling

Toyota has been steadily working with dismantling and recycling companies to ensure compliance with the Law Concerning Measures for End-of-Life Vehicles [4]. The Law mandates automobile manufacturers with collection and recycling/recovery of specified items generated from end-of-life vehicles: CFCs/HFCs, airbags and ASR, (Figure 4.)

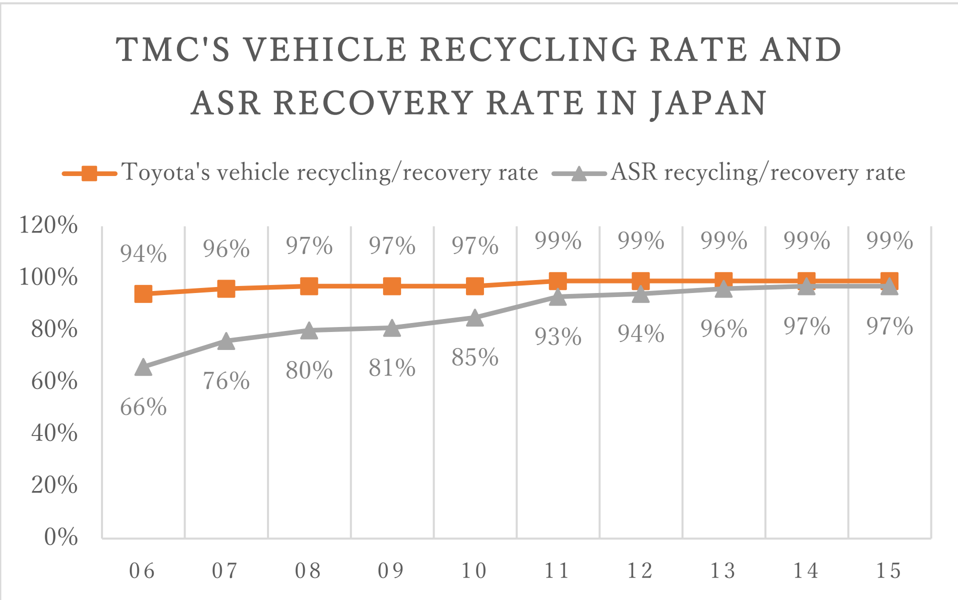


Figure 4. TMC's Vehicle recycling rate and ASR recovery rate in Japan
(Data collected by the author from reports of Toyota company)

These all achievements during 2003-2015 years were great contribution to Recycling-based Society. But the company has been going forward to contribute more toward the Realization of a Circular Economy. They formulated the Toyota Environmental Challenge 2050 in October 2015 and the 2030 Milestone in 2018 so that can face these issues and continue to tackle challenges from a long-term perspective of the world 20 and 30 years ahead. Also, in 2020 Toyota set the 2025 Target as the most recent target of the Toyota Environmental Action Plan, a five-year plan for achieving this.

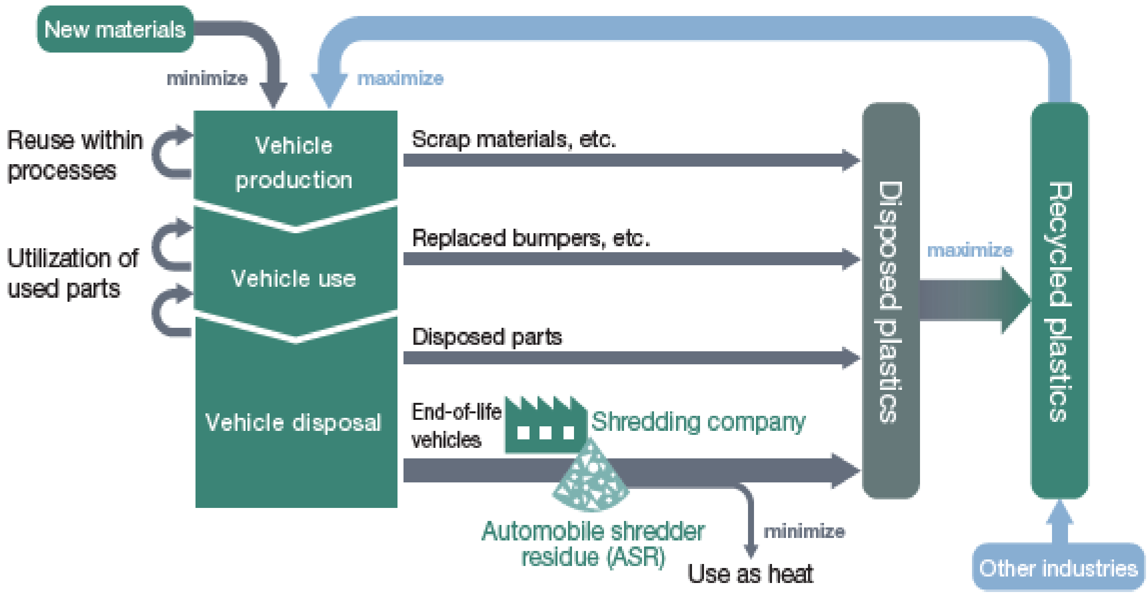
As an initiative to tackle resource-recycling issues under the Toyota Environmental Challenge 2050, formulated "Challenge of Establishing a Recycling-based Society and Systems", and started actions in 2015, placing particular importance on the two projects below in the Challenge of Establishing a Recycling-based Society and Systems:

• Toyota Global 100 Dismantlers Project: To establish social systems for appropriate treatment and recycling of end-of-life vehicles with reduced environmental impact.

• Toyota Global Car-to-Car Recycle Project: A resource recycling initiative throughout the entire vehicle life cycle [15].

3.1.4 Recycling of End-of-life Vehicles Recycled plastics.

According to above mentioned projects Toyota is aiming to increase the use of recycled plastics by more than three times compared to current levels by 2030, with the aim of building a society in 2050 that maximizes plastic recycling on a global scale. Besides, Toyota aims to reuse automobile shredder residue (ASR) from end-of-life vehicles also as a material, which until now has been reused as heat, they are planning to use recycled plastic materials from ASR in new vehicles by utilizing crushing and sorting technologies of Toyota Metal Co., Ltd. They adopt recycled plastics, in stages, into new models that will go on sale in 2022 and afterward, aiming to more than triple the use of recycled plastics by 2030.



Picture 1. Maximization of Utilization of Recycled Plastics in Toyota Vehicles [17]

3.1.5 Resource Recycling of Rare Metals and Rare Earth Elements

With a view to curbing the use of natural resources, Toyota promotes the collection of rare resources used in electrified vehicles such as hybrid electric vehicles (HEVs), plug-in hybrid electric vehicles (PHEVs) and fuel cell electric vehicles (FCEVs), and the reuse of recycled materials. They are collaborating with partner companies to establish a system for collecting and recycling HEV batteries and motor magnets, along with tungsten carbide tools and other materials used in production, aiming to achieve the ultimate goal of closed-loop recycling [14].

3.1.6 Using Biosynthetic Rubber in Engine and Drive System Hoses

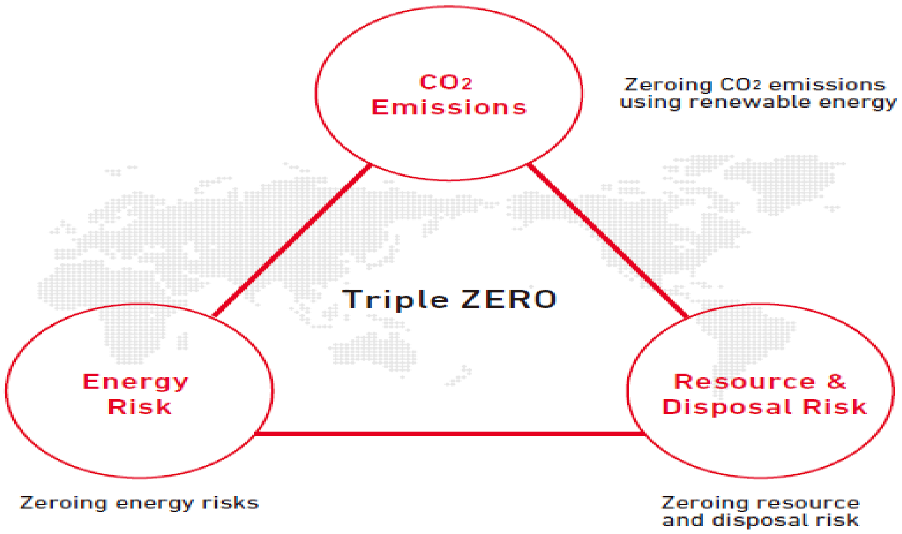
Toyota has become the first automaker to use biohydrin, a newly-developed biosynthetic rubber product, in engine and drive system hoses. Biohydrin rubber is manufactured using plant-derived bio-materials instead of epichlorohydrin, a commonly-used epoxy compound. Since plants absorb CO2 from the atmosphere during their lifespan, such bio-materials achieve an estimated 20% reduction in material lifecycle carbon emissions in comparison to conventional petroleum-based hydrin rubber.

Picture 2. Pioneering use Biosynthetic Rubber in Engine and Drive System Hoses

Using biohydrin rubber in vehicles represents a small but important step toward meeting a range of ambitious environmental targets collectively referred to as the Toyota Environmental Challenge 2050. These targets represent the company's comprehensive map for contributing to global environmental sustainability. Toyota will continue to develop and commercialize technologies that enable the use of materials like ecologic plastics and biosynthetic rubber in a wider range of components [19].

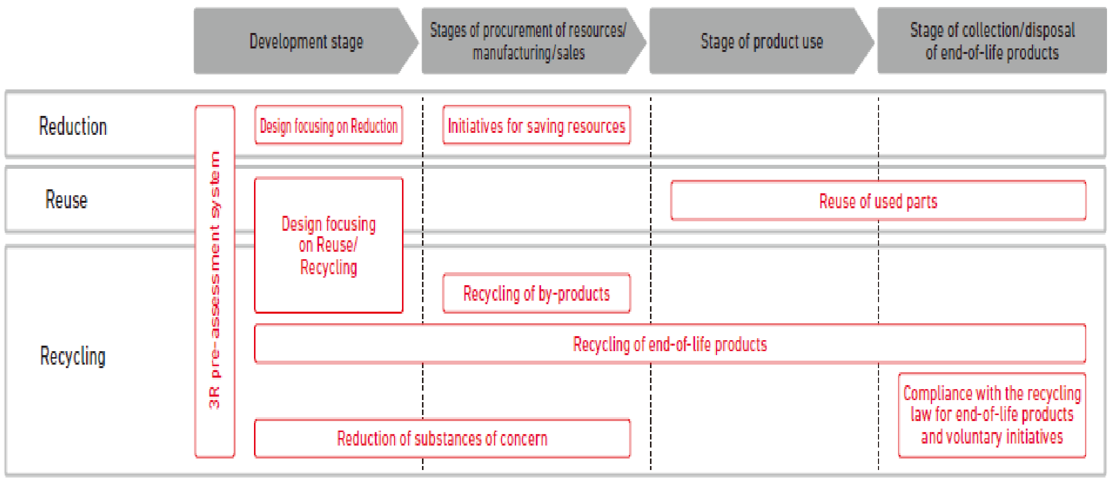
3.2 Honda

In 1992, Honda's Environment Statement was released to serve as the company's guideline for all environmental initiatives. The statement articulates the basic stance Honda had developed until then to reduce environmental impact at every stage in the life cycle of its products, from product procurement to design, development, production, transportation, sale, use and disposal stages. In addition, for Honda to further promote the above-mentioned environmental initiatives and continue to be a company that society wants to exist, the Honda Environmental and Safety Vision was established in 2011. In order for people to live on the earth in a sustainable manner, Honda seeks to realize a recycling-based society with zero environmental impact [20]. Honda has introduced the Triple ZERO concept to unify its three "zeroing" efforts addressing "climate change issues," "energy issues" and "efficient utilization of resources," the most important challenges. The company is striving to realize a society with an environmental impact of zero by engaging in its business activities based on this approach.



Picture 3. Triple Zero Concept [16]

Therefore, according this approach Honda considers the efficient utilization of resources as one of the material issues and is actively promoting 3R (reduction/ reuse/recycling) activities as well as ensuring proper processing when disposing of end-of-life products.



Picture 4. Initiative for the elimination of risks related to resources and disposal [21]

3.2.1 3R Pre-Assessment System

Honda introduced the 3R pre-assessment system, which assesses the 3R elements of each model to be newly developed in the stage of product development, for motorcycles in 1992 and for automobiles in 2001. The Company is striving to improve the level of 3R elements.

3.2.2 Design Focusing on Reduction

Honda is making efforts in downsizing and weight reduction by considering alternative structures and materials for all components in each product, such as the body framework, engine and bolts. For example, the Company used thinner structural bumpers in the N-WGN, which was launched in 2014, as part of a reduction-oriented design geared toward creating a lighter product. The availability of materials with higher rigidity and fluidity along with advances in manufacturing technologies allowed Honda to reduce the weight of the previous design by approximately 20%, which had an average thickness of 3.0 mm, by using less resin in bumper production.

3.2.3 Design Focusing on Reuse/Recycling

Honda is engaging in structural design that takes into account easier recycling and maintenance, use of easily recyclable materials and recycled resins, and display of contents of materials for resin/rubber components, etc. For automobiles, the Company uses easily recyclable materials for a wide array of exterior/interior components, such as inner weather-stripping and the outer surface of instrument panels, and at the same time have enabled the use of recycled materials for air conditioner ducts. In addition, they label resin and rubber parts with their constituent materials wherever possible to facilitate recycling. As a result of the activities mentioned above, with regard to the recyclable rate for all new and redesigned vehicles sold in 2018, Honda is maintaining more than 90% for automobiles and more than 95% for motorcycles, as well as a recoverability rate of more than 95% for components/materials used in power products [21].

3.2.4 Recycling of End-of-Life Components

Honda collects and recycles end-of-life components generated from repair, replacement, etc., from dealers nationwide. In 2018, the Company collected and recycled approximately 160,000 end-of-life bumpers. Collected bumpers are recycled and used for splash guards and other components of the Freed model. Honda will continue the recycling of end-of-life components, including the collection/ recycling of end-of-life hybrid vehicle drive batteries.

3.2.5 Initiative for Automobiles

The Act on Recycling, etc., of End-of-Life Vehicles (automobile recycling law) requires automakers to collect and properly treat three items: fluorocarbons, airbags and shredder dust (Automobile Shredder Residue (ASR)). In 2018, the number of Honda automobiles collected was approximately 490,000 for fluorocarbons (+11% from the previous fiscal year), approximately 460,000 for airbags (+10%) and approximately 520,000 for ASR (+6%). Recycling rates for gas generators and ASR were 93.9% and 98.1%, respectively, which satisfy the recycling rates specified by ordinance of the relevant ministry (at least 85% for gas generators and at least 70% for ASR) [22].

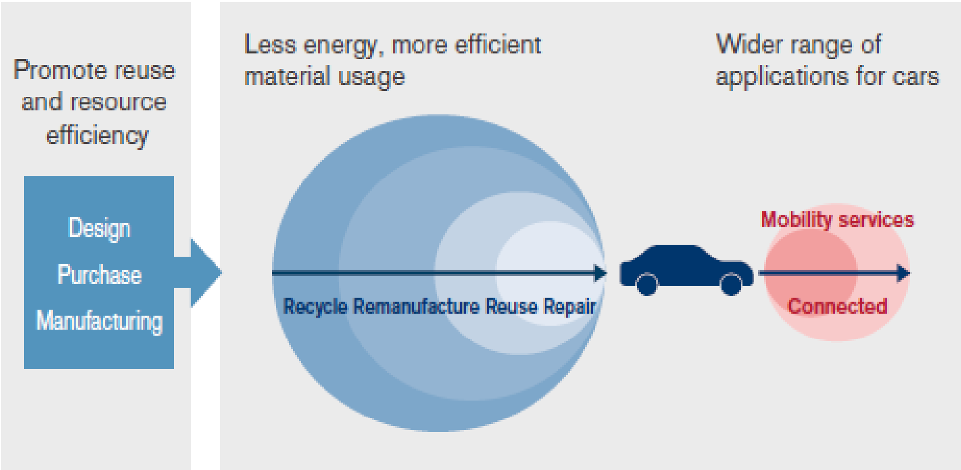
3.2.6 Initiative for Motorcycles

Honda joined hands with other motorcycle manufacturers in Japan and participating motorcycle importers and started to implement the voluntary recycling of motorcycles in October 2004. With the cooperation of related dealers, various companies in the motorcycle industry started this scheme for providing a safety net for the treatment of end-of-life motorcycles, the world's first of its kind. End-of-life motorcycles are collected at the dealers and the designated points of collection free of charge and are properly recycled at recycling facilities. Regarding end-of-life motorcycles collected at designated points of collection, there were 1,020 Honda products in 2018, which accounted for 59.2% of all units collected. The recycling rate of Honda products came to 97.4% on a weight basis, enabling to achieve the target recycling rate of 95% since 2014 [23].

3.3 Nissan Motor Corporation

In order to use the earth's precious and limited resources efficiently, the environmental impact when extracting these resources must be kept to a minimum. At the same time, waste generated during vehicle production and scrap from end-of-life parts must be recycled as extensively as possible without compromising quality, producing materials that can be used in the same types of products. Based on this approach, known as closed loop recycling, company has focused its efforts on recycling steel, aluminum, and resin - three kinds of material which account for a large proportion of vehicle content yet also have a major impact on the environment.

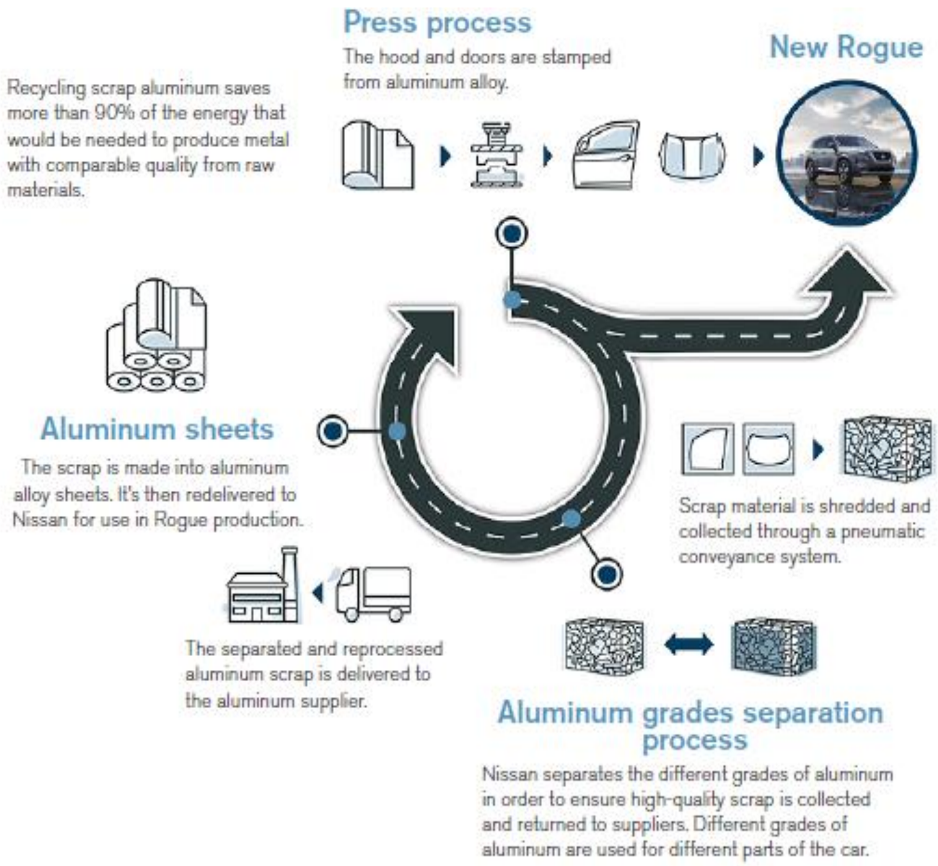
As part of the Nissan Green Program 2022 (NGP2022), Nissan is developing systems for using resources efficiently and sustainably across their entire life cycle, and has adopted the concept of the "Circular Economy" to maximize the value it provides to customers and society. In an attempt to use resources efficiently with less energy, they will promote the use of recycled materials and recycling end-of-life vehicles, and strive to incorporate reusable resources in our activities at the design, purchasing, and manufacturing stages. They are using fewer resources overall, both through appropriate use of chemical substances and making vehicles more lightweight. The company will continue to promote the efficient use of resources with further reduced energy requirements and the expanded use of repaired and remanufactured parts as well as the secondary use of EV batteries in the vehicle use stage, and foster the development of biomaterials and die less forming technology for practical use. Nissan will also increase the value cars manufactured in this way provide to society and ensure that cars can be put to best use by promoting electrification and autonomous drive in its products, pursuing connectivity and providing mobility services such as ride sharing [24].



Picture 5. Nissan's Circular Economy Concept

3.3.1 Initiatives to Expand Use of Recycled Materials (Ferrous and Nonferrous Metals)

In 2021, ferrous metals accounted for 60% of the materials used in our automobiles by weight. Nonferrous metals made up another 14% and resins 15%, with miscellaneous materials making up the final 12%. To further reduce the use of natural resources, they are advancing initiatives to expand the use of recycled materials in each of these categories.



Picture 6. Ferrous and Nonferrous Metals' recycling process [25]

3.3.2 Initiatives to Expand Use of Recycled Materials (Resins)

In addition to initiatives to expand the use of recycled steel and aluminum, Nissan also strives to use more recycled resins. These recycled resins have been given new life as bumpers in the Nissan LEAF and many other new vehicles. Additionally, exchanged bumpers collected from dealerships are being recycled as materials used in under covers and for other components. They collected and recycled approximately 93,000 bumpers in 2021, representing 63.0% of bumpers removed at Japanese dealerships. Furthermore, 30% of the automotive shredder residue (ASR) processed at dedicated processing plants is made from resins. In order to use these resins in automobiles, they are running a number of R&D projects on topics such as like optimizing the recycling process for resins recovered from ASR, and conversion of auto waste plastic into oil.

Picture 7. Resin recycling process [25]

3.3.3 End-of-Life Vehicle Recycling

Nissan considers the 3Rs: reduce, reuse, and recycle from the design stage for new vehicles. Since 2005, all new models launched in the Japanese and European markets have achieved a 95% or greater recyclability rate. They have also joined forces with other automotive companies to promote the recycling of end-of-life vehicles (ELVs) through dismantling and shredding. Based on Japans End-of-Life Vehicle Recycling Law, Nissan has achieved at least 95% effective recycling rate of ELVs in Japan since 2005. In 2021, they achieved a final recovery ratio for ELVs of 99.4% in Japan, greatly exceeding the target effective recycling rate of 95% set by the Japanese government.

ELV processing consists of 4 phases. First, Nissan ELVs entering the dismantling process are recycled, including flat steel, cast aluminum, bumpers, interior plastic parts, wire harnesses, and precious rare earth metals. Second, specific items such as lithium-ion batteries are collected individually and directed to a dedicated recycling process. Third, residues from the dismantling process are crushed and the metallic portions recovered. Fourth, the resulting ASR is turned into recycled materials. Since 2004, Nissan and 12 other Japanese auto manufacturers have supported ASR recycling facilities, as called for in Japan's End-of-Life Vehicle Recycling Law, as an integral part of a system to recycle ASR effectively, smoothly, and efficiently. Nissan is taking an important role in this joint undertaking [25].

3.3.4 Developing Biomaterials

Nissan is promoting technical research to replace plastics and other resin materials used in automobiles with biomaterials derived from plants. Nissan Green Program 2022 contains concrete goals for biomaterials development, and these materials are already being used in cars. For example, the coverings on the seats in the Nissan LEAF are made using biomaterials [25]

Picture 8. Seat coverings made from biomaterials in Nissan LEAF

3.3.5 Proper Use of Regulated Chemical Substances

Nissan revised its standard for the assessment of hazards and risks in the Renault-Nissan Alliance, actively applying restrictions to substances more stringent than existing regulations in areas of growing concern around the world. As a result, the number of substances covered by the Nissan Engineering Standard in 2021 rose to 5,304. These steps are thought to be necessary for future efforts in the repair, reuse, remanufacture, and recycle loop for resources.

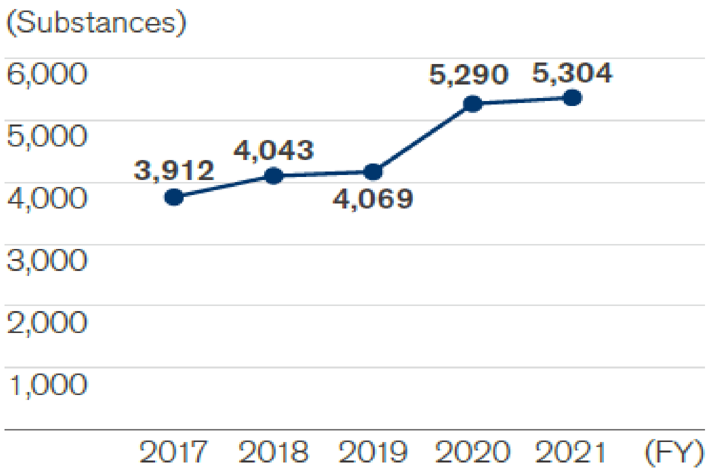


Figure 5. The usage of regulated chemical substances [26]

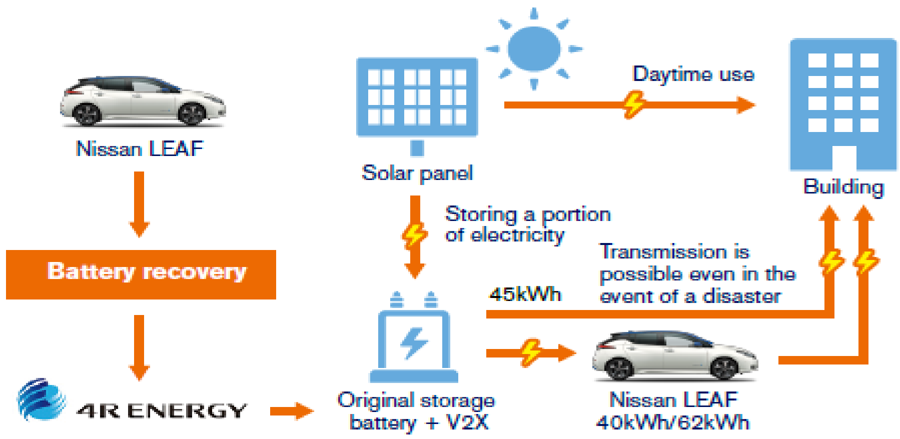
3.3.6 Expansion of Remanufactured Parts

Parts with the potential for recycling include those reclaimed from ELVs, as well as those replaced during repairs. In Japan, they collect and thoroughly check the quality of these secondhand parts. Those that receive a passing grade are sold through our retail outlets as Nissan Green Parts. They sell these parts in two categories: remanufactured parts, which are disassembled and have components replaced as needed, and reusable parts, which are cleaned and tested for quality before sale. In NGP2022, they are enhancing the deployment of Nissan Green Parts in Japan, and are also strengthening management to deploy similar kinds of activities in Europe and North America, aiming for twice the parts coverage in 2022 compared to 2016. This initiative provides customers who seek to use cars for a long period of time with the new option of using remanufactured parts.

Picture 9. The types of Green Parts [26]

3.3.7 Joint Venture to Promote Second-Life Use for Batteries

Lithium-ion batteries used in Nissan's EVs retain capacity well beyond the useful life of the vehicles themselves. The "4R" business models, which reuses, refabricates, resells, and recycles lithium-ion batteries, allows for their effective use as energy storage solutions in a range of applications, thus creating a much more efficient energy cycle of battery use (Pic.10).



Picture 10. The concept for procuring Electricity through Renewable Energy [26]

4. Conclusion

Japan has been the pioneer in the field of ELV recycling, created well-rounded laws and regulations on the industry, and developed advanced know-hows to cope with technical challenges. Therefore, this study tries to summarize the laws and regulations and the latest industrial status of ELVs recycling in Japan. While conducting this research we use annual reports of car companies trying to show real achievements in the context of CE. By this way we can take some pictures about the current situation in the car industry in terms of circular economy and report that Japanese car companies actively promote measures based on the 3R (Reduce, Reuse, Recycle) approach in their production processes whenever possible, striving to minimize the waste generated and maximize recycling efficiency. Given tables, pictures and figures show us that these companies have achieved until now enough big results in this direction and they continue to take actions toward green economy by implementation 3R, 4R and 5R concepts step by step into all production processes.

This research aims to show the progress in the activities of car manufacturers within a circular economy context. In this research only current situation of Japanese automobile industry were studied by three companies, however, we can't make a full conclusion not considering other vehicle manufacturers. Accordingly, our future research will be forwarded to study other Japanese car companies' situation to get a clear image of the problems and achievements in terms of the circular economy.

Acknowledgments

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Circular Economy Policy Trends and Case Studies in Japanese Electronics Industry

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Abstract

The Japanese government aims to capture growth markets with efficient use of limited resources by accelerating circular economy initiatives through public-private partnerships. Recognizing that the shift to a circular business model has the potential to enhance the sustainability of corporate business activities and become a new source of competitiveness, the government urges companies to position this business model as a management strategy and business strategy. In order to support the shift to this model, the government has indicated its policy that it will minimize regulatory methods and leave it to the voluntary efforts of industry while utilizing soft laws such as guidelines.

In response to this policy, the Japan Business Federation ("Keidanren"), the headquarters of Japanese industry associations, has formulated a voluntary plan for the formation of a recycling-oriented society, conducts an annual follow-up survey of the progress, and announces its results. However, since a wide variety of industry associations are members, specific targets such as the amount of final disposal of industrial waste and the amount of reduction in plastic use are set individually by each industry association according to their respective circumstances. The Japan Electronics and Information Industry Association, an industry association for electrical, electronic components, and consumer electronics companies, has set its own targets for the amount of final disposal of industrial waste and for plastic related issues. It is also working to reduce the environmental impact throughout the life cycle of products, such as resource-saving design, and is promoting activities aimed at developing new recycling technologies in order to improve the recycling rate.

Responses to these policies at the individual company level vary. While some companies are making efforts to shift their business models from goods to providing services, many companies are limited to reducing or eliminating the use of plastics or replacing them with environmentally friendly materials. The current situation is that the shift to a highly cyclical business model is still only halfway through in Japan.

Keywords: METI, MOE, Keidanren, JEITA, Consumer Electronics

1. Introduction

As the world's population grows rapidly, the demand for resources, energy, and food is expanding, and a large amount of waste is being discharged. The damage to natural resources and environment is becoming more serious, and global issues such as global warming and marine plastic litter are becoming apparent. With the globalization of economic activities, waste and environmental problems are no longer problems at the regional level, and it is urgent for Japan to take measures in cooperation with other countries.

On the other hand, looking at the world, there is a movement to build international competitiveness by shifting economic activities to a cyclical model that aims to maximize added value through services while reducing resource input and consumption in response to such global issues. In Japan, all parties, including government, industry associations, and companies, need to work together to keep up with global trends while having a strong awareness of how to respond to such global challenges.

This paper examines the Japanese government's policies as well as the initiatives of industry associations and individual member companies, and then discusses Japan's position on the transition to a circular economy, its coming challenges, and its future prospects.

2. Policies of Japanese government

The formulation of national policies for a circular economy is mainly related to two government agencies, the Ministry of Economy, Trade and Industry (METI) and the Ministry of Environment (MOE). The METI is in charge of administration related to economic and industrial development and the supply of natural and energy resources, while the MOE is in charge of policies related to environmental conservation and pollution prevention. The circular economy represents a society that aims to achieve both economic development and environmental protection, and the two government agencies in charge of economic and environmental policies work together to realize it. This section will review the contents of the "Circular Economy Vision 2020" announced by the METI and the "Transition to a Circular Economy" announced by the MOE respectively, and look at the Japanese government's policy toward a circular economy from both economic and environmental perspectives.

2.1 Circular Economy Vision 2020 (METI)

In May 2020, the METI announced the "Circular Economy Vision 2020"(METI, 2020). After evaluating the achievements of the "Circular Economy Vision 1999" formulated about 20 years earlier, it presents the direction of Japan's concrete response toward the circular economy, taking into account recent changes in the global economy and society as well as policies and trends in other countries.

2.1.1 Evaluation of the achievements of the Circular Economy Vision 1999.

The Circular Economy Vision 1999 proposed the full-scale introduction of three measures (3Rs): recycling, reduction and reuse of wastes with the aim of shifting from a linear economic system of mass production, mass consumption, and mass disposal to a circular economy system in which the environment and the economy are integrated. In response to the Circular Economy Vision 1999, the Law for Promotion of Effective Utilization of Resources was enacted, and individual recycling laws (Containers and Packaging Recycling Law, Home Appliance Recycling Law, Food Recycling Law, Construction Recycling Law, and Automobile Recycling Law) were revised or enacted.

These laws clarify the roles of each entity promoting the 3Rs, and have promoted the establishment of a mechanism for recycling resources, indicating the role of consumers such as long-term use of products, use of products using recycled resources or parts, and separate collection of wastes. As a result of these efforts, waste volume has decreased significantly, and the amount of waste in Japan is at a lowest level compared to other countries. For example, in 2017, the per capita amount of municipal waste generated was 335.8 kg/person in Japan, compared to 746.6 kg/person and 489 kg/person in the United States and Europe respectively. In 2018, Japan's home appliance recycling rate was 93% for air conditioners, 86% for LCD TVs, 79% for refrigerators, and 90% for washing machines (METI, 2020).

2.1.2 The need to transform to a circular economy

In this way, in the 20 years since the Circular Economy Vision 1999, Japan's 3Rs have progressed and achieved some results such as improving the recycling rate, but it must be said that the transition from a linear economy system to a circular economy system is still only halfway through. The market in the field of waste treatment and effective use of resources has not yet become an industry that creates sufficient added value, and has not yet promoted resource circulation as a business. It is necessary to shift beyond the 3Rs as an environmental activity, to an economic activity based on the advanced recycling of resources, that is, a circular economy.

In doing so, the use of digital technology is expected to be a driver for the transition to a circular economy. Business models that utilize AI(Artificial Intelligence) and IoT(Internet of Things) to provide services and solutions are being created one after another. For example, subscription services that integrate products and services to provide value are expanding from the conventional business model centered on product sales.

In addition, advanced waste sorting using AI and logistics efficiency combined with IoT and big data analysis have made it possible to improve the efficiency of the 3Rs themselves. In addition, since the adoption of SDGs (Sustainable Development Goals) by the Unitec Nations, consumers' environmental awareness has increased rapidly, and there is a growing tendency to screen companies based on how they are working on the transition to a circular economy. Further, investors are also playing a role as a driving force for the transition to a circular economy through ESG (Environment, Social and Governance) investments.

In this way, the shift to a circular economic activity not only creates social value in the form of preserving the global environment, but also creates economic value through being appreciated by consumers and investors. It can be said that the shift to a circular economic activity will enhance the sustainability of business activities, become a source of competitiveness building, and lead to the improvement of corporate value over the medium to long term.

2.1.3 Expected direction of Japan

(a) Shift to a highly cyclical business model

As the added value provided by products is shifting from hardware to soft services, shifting to circular economic activities can become a new source of added value for the manufacturing industry.

In other words, as hardware generalization progresses and added value shifts to services and solutions, appealing value throughout the product lifecycle with durability and upgradeability based on long-term use can be a winning strategy for Japanese manufacturing industry. Increased durability means that consumers will purchase a product less often, but will extend the length of time they provide services such as maintenance, upgrades, and support. By providing more value-added services over a longer period of time, it should be possible to build a profitable business model.

In addition, when developing products with enhanced durability, it is possible to utilize the "coordination" that transcends the boundaries of companies in the supply chain with the advanced materials industry, which is the strength of Japan's industrial structure. In this way, companies are required to view the shift to highly cyclical business models as a new business opportunity that leads to a "virtuous cycle of the environment and growth," rather than an extension of the 3Rs as an environmental activity.

(b) Utilization of soft law and voluntary initiatives of industry

Since the 1990s, Japan has established mandatory recycling systems for fields with large waste volumes (containers and packaging, automobiles, home appliances, food, construction), and has promoted voluntary efforts by the industry by utilizing soft laws such as the Act on Promotion of Effective Utilization of Resources and the Voluntary Action Plan. As a result, Japan has become the world's top runner in terms of effective use of resources, such as recycling rates.

The nature of the circular economy and the method of realizing it differ from country to country depending on national characteristics, land conditions, existing infrastructure, etc., and it is essential for companies to have the flexibility to optimize their global operations according to individual market demands. For this reason, there is concern that the introduction of hard-law regulatory measures targeting only domestic business activities will lead to rigidity in firms' efforts, hinder ingenuity and innovation, and lead to a decline in international competitiveness. The effective functioning of industry's voluntary efforts is a major strength of Japan, and in order for companies to flexibly respond to global market changes, it is important to indicate milestones to aim for, minimize regulatory methods, and encourage industry’s voluntary efforts by utilizing soft laws such as guidelines.

(c) Importance of appropriate evaluation from the market and society

Such efforts by companies are effective only when they are understood and supported by the market and society. While consistent with the management philosophy, it is important for companies to proactively disclose their stance on the circular economy, earn the trust and evaluation of the market and society, and transform it to business opportunities. Investors are increasingly evaluating the value of companies and making ESG investments by evaluating not only financial indicators, but also non-financial indicators related to the companies’ attitude on environmental, social, and governance initiatives. Companies can attract responsible investment from a medium- to long-term perspective by positioning and actively appealing initiatives and policies for circular economic activities in their management philosophy and business models.

In addition, in order to shift to a circular economy, it is important to create an environment in which highly cyclical products and business model are appropriately evaluated by consumers. The government has taken measures such as the Eco Mark and the Green Purchasing Law in the past, but the industry also needs to work on setting industry standards for products with cyclical performance, developing labeling systems, and considering incentives for consumers to purchase those products.

Of course, it is most important for consumers to raise their own environmental awareness. In addition to taking the initiative in purchasing products with low environmental impact, consumers are required to be aware that they are members of the circular economy system and to promote changes in their consumption behavior and lifestyles, such as minimizing waste emissions. It is also important to lead consumers to a recycling-oriented lifestyle by promoting educational activities in various places in society, including environmental education in schools.

(d) Building a resilient circulation system

The environment surrounding waste disposal and resource recycling in Japan is becoming increasingly severe. Restrictions on waste imports by China and other Asian countries, declining prices of recycled resources, increasing logistics and treatment costs, and the reduction of domestic production facilities of the steel and cement industries, which have previously accepted waste as raw materials, make it difficult to maintain the current circulation system.

It is necessary to rebuild Japan's circulation system from a medium- to long-term perspective, and to work on building a resilient circulation system that balances maximum utilization of domestic circulation and complementary securing of international circulation. What is necessary for this is the advancement and diversification of collection, dismantling, and sorting technologies for recycling. It is also necessary to develop standards for the use of recycled materials, review regulatory standards, and develop certification schemes so that the use of recycled materials is evaluated as environmental value. Furthermore, in order to build an international circulation system that complements domestic circulation, it is necessary to evaluate the ideal certification system for international resource circulation.

2.2 Circular Economy Policy (MOE 2022)

2.2.1 Legal system for forming a recycling-oriented society

The Basic Law for the Formation of a Recycling-Oriented Society (Basic law on Recycling) is a law that stipulates the basic principles for the formation of a recycling-oriented society (MOE, 2022a). This law was enacted in 2001 and clearly states the image of a recycling-oriented society that curbs the consumption of natural resources and reduces environmental impact, and legally stipulates the priority of cyclical use of resources and waste disposal ((1) generation control, (2) reuse, (3) recycling, (4) heat recovery, and (5) proper disposal). In addition, under this law, a recycling-oriented society is defined as "a society in which the consumption of natural resources is suppressed and the burden on the environment is reduced as much as possible by suppressing the turning of products from becoming waste, using the discharged waste as appropriately as a resource, and finally ensuring that what cannot be used is properly disposed of."

Under the Basic Law on Recycling, the Law for Promotion of Effective Utilization of Resources stipulates the recycling of resources, and the Waste Disposal Law stipulates the proper disposal of waste. In addition, there is an individual recycling law that regulates these efforts according to the characteristics of individual goods. These legal systems characterize Japan's environmental protection efforts centered on the 3Rs.

2.2.2 Initiatives for the Circular Economy

In addition to these 3R initiatives to protect the environment, the circular economy is an economic activity that creates added value through the conversion of services while effectively utilizing stock and reducing resource input and consumption. It also aims to maximize the value of resources and products, minimize resource consumption, and prevent the generation of waste. In Japan, under various laws and regulations to promote the formation of a recycling-oriented society, various achievements have been accumulated through the cooperation of various entities such as the government, the business community, and the public. In March 2021, the MOE and Keidanren launched the Circular Economy Partnership, a public-private partnership aimed at accelerating circular economy initiatives.

In addition, the MOE, together with the World Economic Forum (WEF), held the "Circular Economy Roundtable Meeting" on March 2021 to disseminate to the world the technologies and initiatives related to the circular economy of Japanese companies. Going forward, it is necessary to promote circular economy initiatives through public-private partnerships by companies accelerating resource recycling as part of their business strategies, and by government developing necessary legal systems and disseminating Japan's advanced technologies and solutions both domestically and internationally (MOE, 2022b).

2.2.3 Realization of plastic resource recycling strategy

Three major measures are being implemented for plastic resource recycling. The first is the promotion of resource recycling of plastics. In 2019, the government's plastic resource circulation strategy was formulated, and in April 2022, the "Act on Promotion of Resource Recycling Related to Plastics (Plastic Resource Recycling Law)" was enforced to realize it.

The second is the introduction of bioplastics. In January 2021, “Bioplastic Introduction Roadmap” was formulated, which summarizes necessary measures such as basic policies for the introduction of bioplastics, support for production equipment and technology development, and demand stimulation through government initiatives, in order to improve the practicality of bioplastics and promote their replacement with fossil fuel-derived plastics.

The third is the formulation of ESG guidance in the field of plastic resource recycling. In January 2021, the "Guidance for Disclosure and Dialogue for Promoting Sustainable Finance in the Circular Economy" was released as ESG guidance for both investors and companies in the field of plastic resource circulation. It is expected that companies that take the initiative in plastic resource recycling are appropriately evaluated by investors engaged in ESG finance and a common foundation that leads to improvement of corporate value and international competitiveness is developed.

2.2.4 International cooperation to solve the problem of marine plastic litter

At the G20 Osaka Summit held in June 2019, Japan proposed the "Osaka Blue Ocean Vision," which aims to reduce additional pollution from marine plastic litter to zero by 2050, which was shared among the leaders. In order to solve the problem of marine plastic litter, it is necessary for the entire world, including emerging and developing countries in Asia, to take countermeasures because there are many outflows from these countries. Japan called on countries other than the G20 to share the vision, and as of March 2021, 86 countries and regions share the vision.

In order to realize the vision, the “G20 Framework for Implementing Marine Plastic Litter” was adopted and approved by the G20 leaders at the G20 Ministerial Meeting on Energy Transitions and Global Environment for Sustainable Growth held in June 2019. Based on the implementation framework, countries will regularly share information on countermeasures and implement effective measures through mutual learning.

2.2.5 Sustainable waste disposal

Due to declining birthrate, aging population, and depopulation in rural areas, there are concerns about a shortage of waste disposal personnel and inefficiency of waste disposal in local areas. In addition, due to the aging of waste treatment facilities, it is necessary to review the waste treatment system, including facility renewal, in many regions.

In light of these circumstances, in order to ensure the sustainable and proper disposal of waste into the future, it is necessary to once again promote the establishment of a stable and efficient waste disposal system in the region. In order to ensure sustainable and proper disposal, it is necessary to improve the efficiency of facility development, maintenance, and management by widening and consolidating general waste treatment facilities. It is also necessary to utilize them as regional energy centers by recovering waste energy, use them as disaster prevention bases in the event of a disaster, and provide opportunities for environmental education and learning through tours of treatment processes. It is expected to build a waste treatment system that creates new value in the region as the core of the regional circulating and ecological sphere.

3. Policies of Japanese Industry Associations

As indicated in the previous section, the government believes that the transition to a circular economy is important for domestic companies to capture growing markets and build medium- to long-term competitiveness, and urges companies to work on creating circular business models. By minimizing hard-law legal regulations and utilizing soft-law guidelines, the basic policy of government is basically to leave it to the voluntary efforts of industry. Then, how is the industry trying to deal with such a government policy? First, this section will look at the policies of Japan Business Federation (“Keidanren”), which is the headquarters of industry associations in Japan.

3.1 Policies of Keidanren

3.1.1 Voluntary Action Plan for the Formation of a Recycling-Oriented Society

In 1997, the Keidanren formulated the "Voluntary Action Plan on the Environment" for waste countermeasures. It included numerical targets for each industry and specific measures to achieve the targets, and since then, the progress has been followed up by each industry every fiscal year. In 2007, it was expanded and re-formulated as the "Voluntary Action Plan for the Formation of a Recycling-Oriented Society" with the aim of promoting not only waste countermeasures but also a wide range of industrial efforts to create a recycling-oriented society (Keidanren, 2021a).

As of year 2022, 45 industries are participating in this plan, and three types of targets have been set for each participating industry: (1) targets for reducing the amount of final disposal of industrial waste, (2) industry-specific targets, and (3) industry-specific plastic-related targets. The Keidanren conducts a follow-up survey of them every fiscal year and publishes the results (Keidanren, 2022a). As for the target for reducing the final disposal amount of industrial waste, in addition to the target for each industry, the Keidanren as a whole has set a target of 75% reduction by 2025 compared to the actual amount of 2000.

As for industry-specific targets, based on the characteristics and circumstances of each industry, targets are set for each industry, such as the recycling rate of by-products generated in the product manufacturing process and the amount of reduction in general business-related waste. In addition, industry-specific plastic-related targets have been set for each industry, such as those that contribute to solving the problem of marine plastics and promoting plastic resource recycling.

3.1.2 Japan Partnership for Circular Economy

In March 2021, Keidanren, in collaboration with the MOE and the METI, established the Partnership for Circular Economy with the aim of further fostering understanding of the circular economy among its member companies and promoting their initiatives (Keidanren, 2021b). Specific activities include collecting case examples of Japan's advanced circular economy initiatives, disseminating information domestically and internationally, sharing information on the circular economy, forming networks, and setting up a forum for dialogue to promote the circular economy. By holding a ceremony every year to announce notable case examples and disseminating them to the world, the partnership aims to appeal Japan's outstanding efforts and reflect them in global rulemaking (Keidanren, 2022b).

3.2 Japan Electronics and Information Technology Industries Association(“JEITA”)

JEITA, a constituent organization of Keidanren, is an industry association whose members include electronics, electronic components, and consumer electronics companies. In accordance with the Voluntary Action Plan for the Formation of a Recycling-Oriented Society established by Keidanren, JEITA has set its own industry-specific targets for the reduction amount of final disposal of industrial waste, final disposal rate targets, and plastic-related waste reduction targets. Followings are initiatives to create a recycling-oriented society.

3.2.1 Initiatives to reduce environmental impact throughout product life cycles

Based on the Home Appliance Product Assessment Manual, consumer electronics companies are engaged in product assessments that take into account designs for resource savings, designs for long time use by adopting long life parts, and designs which are easy to recycle by using recycling-friendly materials. In addition, for six items of home appliances (air conditioners, refrigerators and freezers, TVs, washing machines, clothes dryers, and electronic lenses), based on the Home Appliance Product Assessment Manual, plastic parts weighing 100 g or more are labeled with materials to make them easier to separate when recycling.

3.2.2 Development and commercialization of technologies that contribute to the effective use of resources

By collecting household appliance waste based on the Home Appliance Recycling Law and developing new recycling technologies, the recycling rate has increased. In this way, the proper treatment and reduction of waste and the effective use of recycled resources are being promoted within the industry.

3.2.3 Establishment of the Green x Digital Consortium

In October 2021, JEITA established the Green x Digital Consortium, which aims to create a new society and market using digital technology. The consortium is promoting activities to create and implement new digital solutions that will lead to industrial and social transformation in order to promote carbon neutrality among companies (JEITA, 2021). Business Federation (“Keidanren”), which is the headquarters of industry associations in Japan.

4. Case Studies of Japanese Electronics Companies

4.1 Panasonic Corporation

Panasonic's Environmental Vision 2050, which is its company-wide environmental policy, advocates both "better lifestyles" and "sustainable global environment." In order to achieve this, Panasonic is working on initiatives based on the concept of eco-design that maximizes the use value of customers by improving resource efficiency in each of the design, procurement, and production processes (Panasonic, 2022).

There are two types of circular economy initiatives promoted by Panasonic: the creation of circular economy-type businesses and the evolution of circular economy-type manufacturing. The former is to embody the new value of using functions rather than things, such as "sharing services" that share one product with many people, "service of things" that enhance services based on functions, and "repair/maintenance, refurbish, remanufacturing” that maximizes the life of product by regenerating and reusing the parts used in the product. The latter includes the reduction of input resources, the utilization of recycled resources, zero emissions in production activities, as well as the evolution of recycling-oriented manufacturing using new materials and the latest digital technology.

As for specific activities, in order to create circular economy-type businesses, they have completed a relationship mapping for all existing businesses that clarifies the relationship between existing businesses and the circular economy, and are working to develop circular economy-type businesses from existing businesses. Furthermore, they are promoting zero-emission activities aimed at achieving a factory waste recycling rate of 99% or more by realizing the characteristics required of the parts, securing a stable supply volume, and accelerating the development of recycling technology. In addition, in order to accelerate these efforts, a circular economy project has been rolled out company-wide since April 2020 with Panasonic Europe as the global promotion leader.

Below are some examples of Panasonic's initiatives listed in the Circular Economy Partnership Case Study (JPCE, 2022a).

(a) Sharing service of IoT electric assist bicycle

(b) Value provision service of refrigeration showcase and refurbishment service

(c) Provision service of light function

(d) Development and deployment of new recycled cellulose fiber molding materials

(e) Development and deployment of environment-friendly flooring materials

4.2 Sony Group Corporation

Sony has formulated the "Road to Zero" environmental plan, which aims to reduce its environmental impact to zero by 2050 throughout its business activities and product lifecycles, in order to conserve the global environment and realize a healthy, spiritually enriched and sustainable society into the future (Sony, 2022a; Sony, 2022b). Based on this plan, Sony has identified important resources in order to minimize the input of new resources in its business activities, and aim to eliminate the use of new materials. In addition, Sony is making effort to collect and recycle products from the market, ensure thorough resource recycling, and minimize final waste.

Sony is responding to the expansion of the market for products that use recycled materials and renewable resources by expanding the introduction of SORPLAS, a flame-retardant recycled plastic developed by Sony, reducing plastic packaging materials, and completely eliminating plastic packaging materials for small products. In addition, by developing and licensing Triporous which use surplus biomass rise husks as a raw material, Sony is trying to develop a new market that contributes to resource recycling.

As specific targets, Sony is working to achieve the following products and services related to the circular economy set forth in the Sony Group's medium-term environmental goals "Green Management 2025." (a) 10% reduction in virgin plastic consumption per product、(b) 10% reduction in plastic packaging material used per product, (c) Completely abolition of plastic packaging materials for newly designed small products.

In order to promote measures such as the manufacture and sale of environmentally friendly products and the implementation of product recycling, Sony has an environmental department at the head office that oversees environmental management for the entire group, and is responsible for establishing goals and rules, monitoring performance, and revitalizing internal communication. The head of the Environmental Division is an executive officer of Sony Group Corporation, and the president of the company shares, discusses, and makes decisions on important environmental issues, including the circular economy, at regular meetings.

Below are some examples of Sony's initiatives listed in the Circular Economy Partnership Case Study (JPCE, 2022b).

(a) Introduction of proprietary flame-retardant recycled plastic SORPLAS to TV rear cover
(b) Conversion of individual packaging boxes of consumer camera accessories into paper boxes
(c) Reduction of plastic packaging for PlayStation 5
(d) Significant reduction in plastic packaging materials for headphones
(e) Wireless noise-cancelling headphones with recycled plastic and eco-friendly packaging

5. Summary

The Japanese government aims to capture growth markets with efficient use of limited resources by accelerating circular economy initiatives through public-private partnerships. Recognizing that the shift to a circular business model has the potential to enhance the sustainability of corporate business activities and become a new source of competitiveness, the government urges companies to position this business model as a management strategy and business strategy. In order to support the shift to this model, the government has indicated its policy that it will minimize regulatory methods and leave it to the voluntary efforts of industry while utilizing soft laws such as guidelines.

In response to this policy, the Japan Business Federation ("Keidanren"), the headquarters of Japanese industry associations, has formulated a voluntary plan for the formation of a recycling-oriented society, conducts an annual follow-up survey of the progress, and announces its results. However, since a wide variety of industry associations are members, specific targets such as the amount of final disposal of industrial waste and the amount of reduction in plastic use are set individually by each industry association according to their respective circumstances. The Japan Electronics and Information Industry Association, an industry association for electrical, electronic components, and consumer electronics companies, has set its own targets for the amount of final disposal of industrial waste and for plastic related issues. It is also working to reduce the environmental impact throughout the life cycle of products, such as resource-saving design, and is promoting activities aimed at developing new recycling technologies in order to improve the recycling rate.

Responses to these policies at the individual company level vary. While some companies are making efforts to shift their business models from goods to providing services, many companies are limited to reducing or eliminating the use of plastics or replacing them with environmentally friendly materials. The current situation is that the shift to a highly cyclical business model is still only halfway through in Japan.

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Novel Approaches towards Circular Construction: A Case for Construction Automation and Robotics

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Abstract

The construction industry, supported by the materials industry, is a major consumer of natural resources. It is highly important to adopt the philosophy of circular economy into the construction sector. Apart from several existing regulations, guidelines, standards, certification frameworks, and subsidies on the EU and national levels, further innovative solutions are needed to further support circular construction in Germany. Automation and robotics have the potential to play a key role in the development of circular construction by increasing productivity, reducing waste, increasing safety, and mitigating labor shortages. Starting with a brief synopsis of the history of construction robotics and the concept of robot-oriented design, this article presents exemplary case studies of research projects and entrepreneurial activities in which the authors have participated that have contributed to the advancement of circular construction. The activities of the authors have systematically led to spin-offs and start-ups, especially in recent years (e.g., CREDO Robotics GmbH, ARE23 GmbH, KEWAZO GmbH, ExlenTec Robotics GmbH, etc.), which shows that the use of construction robots is becoming an important part of the construction industry. With the use of automation and robotics in the built environment, current challenges such as the housing shortage can be addressed using the leading machinery and robot technology in Germany. In connection with new approaches from the field of human-centric use of robots, human labor can be perfectly supplemented in order to compensate for the shortage of skilled workers. Automated construction machinery for infrastructure construction offers highly efficient solutions for the expansion and renovation of roads, railroads, bridges, and tunnels. The knowledge and know-hows gained in these endeavors will lay the groundwork for the next frontier of construction robotics beyond the construction sites.

Keywords: Automated construction machinery, circular construction, circular economy, construction robots, Cradle to Cradle, Robot-Oriented Design.

1. Background

Circular economy is an economic model that aims to minimize waste and pollution by designing products and processes in a way that resources are kept in use for as long as possible. It focuses on reusing, repairing, refurbishing, and recycling materials and resources, instead of using them only once and disposing them. The concept can date back to the modern environmental movement of the 1960s and 1970s (Ekins et al., 2019). It took another few decades before the idea became the main topic of the emerging research field of industrial ecology. Milestone literature includes Biomimicry (Benyus, 1997), Cradle to Cradle (Mcdonough and Braungart, 2002), and Towards the Circular Economy (Ellen

MacArthur Foundation, 2013), which first illustrated the renowned "butterfly diagram" (see Figure 1). To date, the concept has become a mainstream topic with the academia still trying to catch up.

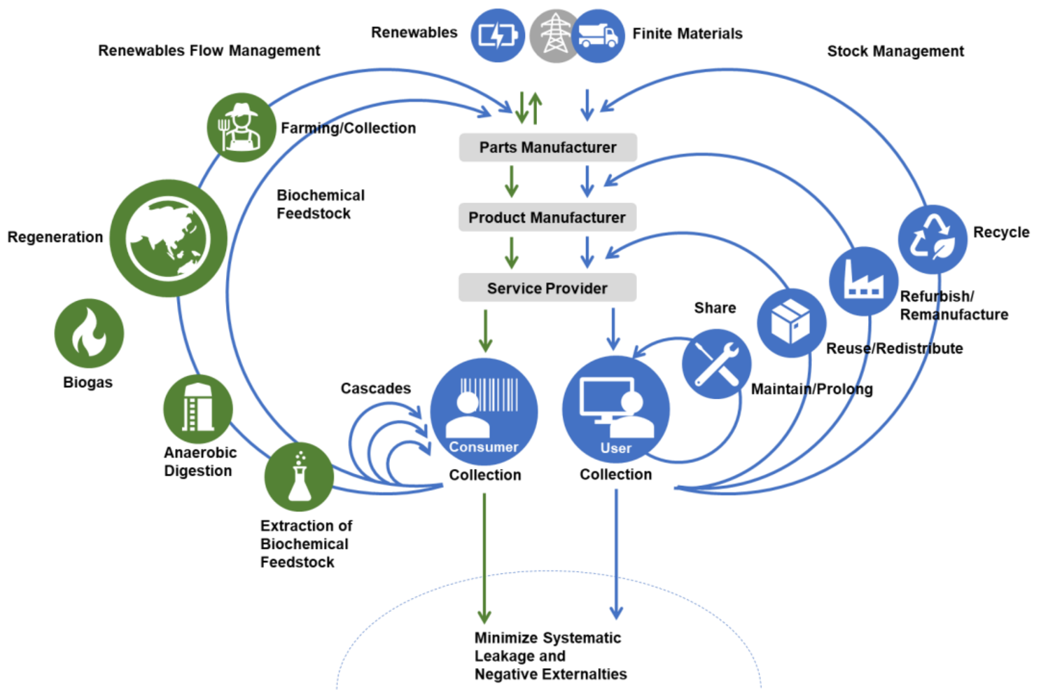

Figure 1 Circular economy systems diagram (adapted from Ellen MacArthur Foundation, 2013)

It is widely known that the construction industry, along with the materials production sectors supporting it, is one of the largest exploiters of natural resources on the global stage, both in physical and biological manners (Spence and Mulligan, 1995). Therefore, it is highly important to adopt the philosophy of circular economy into the construction industry. Derived from the concept of circular economy, circular construction refers to the design and construction approach of buildings and infrastructure that prioritizes the use of sustainable and renewable resources, and waste reduction. It aims to create buildings that can be disassembled, and their components reused or recycled at the end of their life cycle, instead of being discarded as waste. This approach aims to close the loop on material use and promote a more sustainable built environment (Rahla et al., 2021; Çimen, 2023).

The following sections will present a brief introduction of the current situation of circular construction in the EU and Germany respectively.

1.1 Circular construction in the EU

According to the European Union, the construction sector in the EU accounts for: 40% of gross final energy consumption; 35% of greenhouse gas emissions; 50% of extracted material resources; 30% of water consumption; and 35% of waste production (European Circular Economy Stakeholder Platform, 2022). Circular economy is a new economic model pushed by the EU as a strategic objective (see EU policy document Closing the loop - An EU action plan for the Circular Economy; Eco-design Work Programme 2016-2019) (European Commission, 2015; European Economic and Social Committee, 2017). In regard to EU's construction sector, the following circular construction policies and regulatory frameworks for building sustainability assessment are worth noting (González, 2021):

- Transversal regulations on Building Sustainability Assessment by CEN TC 350
- European Framework for Building Sustainability Assessment Level
- Cradle-to-Cradle certification scheme
- Environmental Assessment Methodology (BREEAM) circular framework; Leadership in Energy and Environmental Design (LEED) certification

1.2 Circular construction in Germany

The building sector plays an important role in Germany’s energy transition. It accounts for 30% of Germany’s greenhouse gas emissions. Specifically, residential buildings alone are responsible for 26% of Germany’s final energy consumption due to electricity usage and heating. Meanwhile, non-residential buildings are responsible for 47% of Germany’s greenhouse gas emissions, despite comprising only 13% of the building volume (Novikova et al., 2018). Therefore, it is required by Germany’s Energy Concept to reduce 80% of primary energy demand by 2050 compared to 2008 (BMWK, 2011), as well as by Germany’s Climate Action Plan 2050 to cut up to 67% emissions by 2030 compared to 1990 (BMUB, 2016).

The waste management aspect based on closed-loop concept and disposal responsibilities is not new in Germany. The relevant policy has been adopted for more than 20 years. In 2013, there were 339.1 million tons of waste produced in Germany with a total recycling rate of 79%, of which 202.7 million tons are construction and demolition waste. The new German Closed Cycle Management Act (Kreislaufwirtschaftsgesetz, KrWG) aiming at transforming waste management in Germany into resource management came into force on 1 June 2012, which has raised public awareness of closed-cycle waste management even more. (Nelles et al., 2016).

The New Buildings Energy Act (Gebäudeenergiegesetz, GEG) came into force on 1 November 2020, which replaces and unifies the German Energy Saving Act (Energieeinsparungsgesetz, EnEG), the German Energy Saving Ordinance (Energieeinsparverordnung, EnEV) and the German Renewable Energies Heat Act (Erneuerbare-Energien-Wärmegesetz, EEWärmeG). The new law will also be supported by other existing laws and standards (German Energy Agency, 2020).

Furthermore, several voluntary certification frameworks have already been established globally to quantify the environmental impact of specific buildings and reduce it over time. These frameworks include world-renowned LEED and BREEAM certification frameworks, and the system particularly made for the German market, the DGNB (Deutsche Gesellschaft für Nachhaltiges Bauen) certification system.

Other incentives in Germany that are worth mentioning include but are not limited to subsidies provided at the federal and state level, such as (Rheude and Röder, 2022):

- Subsidies provided by the German Credit Institute for Reconstruction with the KfW 55 loan for passive houses;
- Several states have set up/planned a subsidy per ton of biogenic carbon used (e.g., North Rhine-Westphalia, Berlin, Bavaria, Baden-Württemberg).

2. A case for construction automation and robotics

As discussed above, the construction industry, together with the materials industries which support it, is one of the major global exploiters of natural resources. While the need of public housing due to the population explosion is continuously increasing (United Nations, 2019), the material and labor costs are rising. The increased competition and shrinking profit margins are some further challenges facing the construction industry. According to McKinsey Global Institute, the construction industry has an intractable productivity problem. Furthermore, the report confirms that while sectors such as retail and manufacturing have reinvented themselves, construction seems stuck in a time warp. Global labor-productivity growth in construction has averaged only 1% a year over the past two decades, compared with growth of 2.8% for the total world economy and 3.6% in manufacturing (McKinsey Global Institute, 2017). Therefore, using innovative solutions to increase the productivity of the construction sector becomes critical to the sustainability of the construction industry.

Furthermore, the construction sector is responsible for 36% of the energy use and for producing 39% of the global carbon dioxide (CO2) emissions including operational energy emissions and embodied emissions that are resulted from materials and construction processes along the whole life cycle (International Energy Agency, 2019). Take concrete as an example: Invented more than 200 years ago, cement concrete continues to be the most frequently used building material. Its usage globally (in tonnage) is twice that of steel, wood, plastics, and aluminum combined (Cockburn, 2021). The ready-mix concrete industry, the largest segment of the concrete market, is projected to surpass $600 billion in revenue by 2025 (Manjunatha et al., 2021). In addition, concrete production uses substantial amount of energy and raw materials, which results in a large amount of total CO2 emissions (around 7.0%) into the environment (Unis Ahmed, 2022).

More importantly, labor safety in the construction sector is a major issue facing the industry today. The reduction in the number of onsite construction workers at height, through applying construction robots, can substantially reduce the chance of fatal accidents and other injuries on the construction sites. According to Eurostat, there were 3355 fatal accidents at work in EU-28 states during 2020, of which 21.5% happened in the construction sector (Eurostat, 2022). In other words, more than 700 accidental deaths took place within the construction industry in EU countries just in 2020. The reduction in the number of onsite construction workers at height, through applying advanced technologies, can substantially reduce the chance of fatal accidents and other injuries on the construction sites.

In addition, as the global population is continuously aging, the construction industry is expected to bear the brunt for the years to come. In fact, many countries and regions have already experienced labor shortages in the construction sector, especially high-skilled ones (Mohd Rahim et al., 2016; Ceric and Ivic, 2020; Ho, 2016). The fact that the construction industry suffers from a bad public image (also known as "3D": dangerous, dirty, difficult) also aggravates these shortages due to its lack of ability to attract younger workforce. Apparently, novel solutions are needed to mitigate these shortages.

Therefore, improving productivity, reducing waste, enhancing safety, as well as mitigating labor shortages in the construction industry will contribute significantly to the sustainable development of the construction industry. In recent years, several technologies and innovations have already been introduced and implemented in the building sector, including but not limited to new design theories (e.g., passive solar houses, open building), standards (e.g., Cradle to Cradle design, BREEAM, LEED, DGNB), materials (high performance bricks, concrete, glass, insulation), building components (e.g., triple-glazed windows, green facades, greenhouses, sunshades, ventilation), and equipment (e.g., solar panels, heating and cooling systems), to foster the sustainable development of the sector. As a result, construction automation and robotics can also play a significant role in this process, just as it already did in other industries such as manufacturing and agriculture.

3. The rise of construction robots

The construction automation and robotics is a new yet flourishing research topic. Ever since the first stationary construction robotics (see Figure 2) debuted in the 1960s in Japanese modular prefabrication of the legendary Sekisui Heim M1 that was designed by Dr. K. Ohno , then from the late 1970s the first on-site construction robots (see Figure 3) were developed by Japanese general contractor Shimizu Corporation due to the lack of skilled labor, low construction quality, and bad public image, about 50 construction robot systems have been developed in the 1980s. Other catalysts also include high land prices, high interest rates, and high living cost which required rapid, on-time, high quality construction project delivery on site as planned as well as immediate return on investment. As a result, from the 1990s, on automated construction sites (e.g., the pioneering Shimizu Manufacturing System by Advanced Robotics Technology, also known as SMART System, developed by Shimizu Corporation in 1992, see Figure 4) have also become a worldwide research and development topic (Bock and Linner, 2016a).

Figure 2 Stationary use of construction robots in the factory at Sekisui Heim and its legendary M1 model (photo: T. Bock)

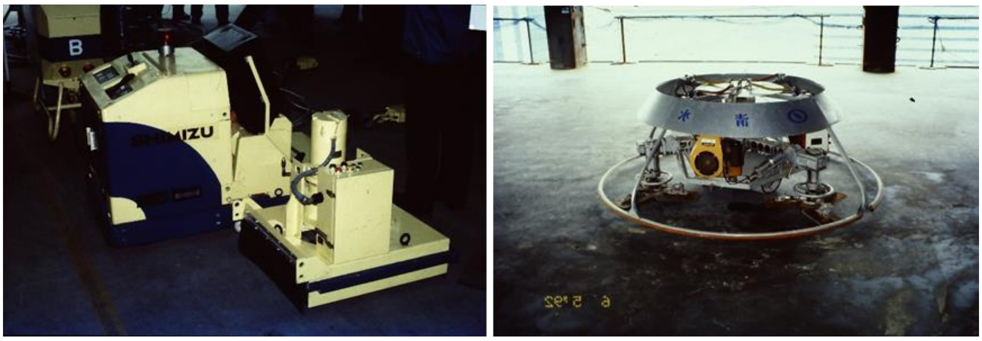

Figure 3 First on-site construction robots developed by Shimizu Corporation (photo: T. Bock)

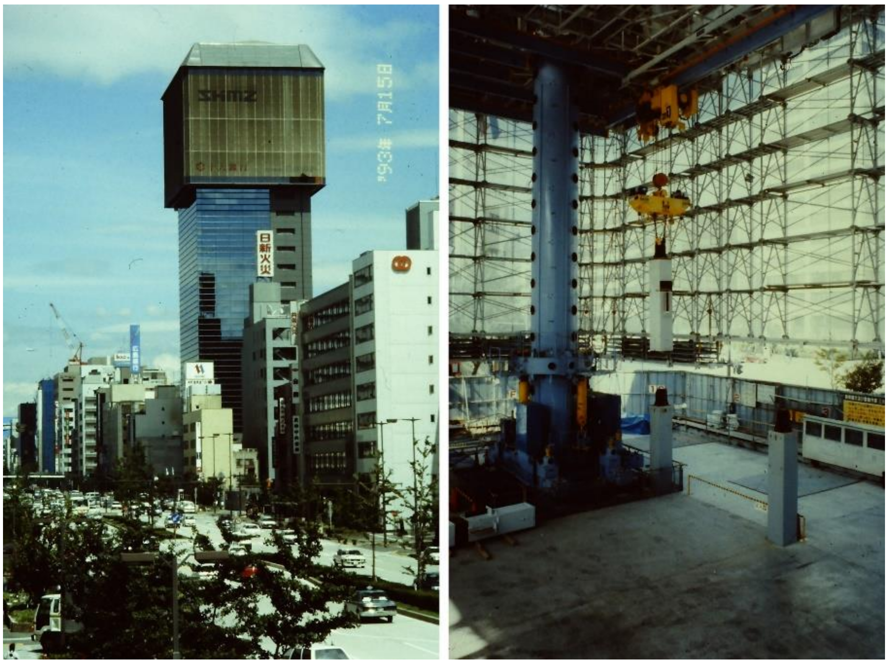

Figure 4 The pioneering automated construction site "SMART" developed by Shimizu Corporation (photo: T. Bock)

Further innovation push was triggered by earthquakes, landslides, volcano eruptions, and tsunamis where initially since 2000s, teleoperated construction robots (see Figure 5) and since 2010s, autonomous scrapers, graders, rollers, compactors, trucks, and excavator fleets for large engineering projects such as dams, roads, bridges and tunnels have been developed and applied (see Figure 6). For maintenance, inspection, and repair of buildings and infrastructure such as tunnels, roads, dams, and power plants, various maintenance robots were developed (see Figure 7).

Figure 5 Teleoperated construction robot for tunnel construction (photo: T. Bock)

Figure 6 Autonomous heavy machinery fleet for infrastructure projects (Photo: T. Bock)

Figure 7 Maintenance robot Enryu T-53 developed by TMSUK Co. Ltd. (photo: T. Bock)

As a national project on circular construction, the Solid Material Assembly System (SMAS, see Figure 8) based on an earthquake-proof reinforced concrete block assembly and disassembly robot was successfully developed and tested at the Building Research Establishment (BRE) of Japan's Ministry of Construction between 1984 and 1988. The robot utilized a FANUC robotic arm with a specially designed end-effector with gripping and bolting functions to better coordinate the vertical reinforcement bolting connections of the customized "Lego-like" concrete blocks (i.e., passive compliance, see Figure 8 right), meanwhile integrating a glass fiber sensor to check the proper position of these connections (i.e., active compliance). A supply pallet system for 8 concrete blocks was also designed to coordinate with the operation of the robot. During this project the co-author T. Bock developed the notion of Robot-Oriented Design, which suggested that architects and engineers should already consider the application of robotic technology on the construction sites when designing the compliant buildings and their elements, eventually achieving shorter on-site assembly time and higher profitability (Bock, 1988). The Robot-Oriented Design concept was applied to the first automated construction site SMART (see Figure 4) and to Obayashi's Automated Building Construction System (ABCS) from 1992 onwards, and also laid the foundation for the development of many construction robot systems. Furthermore, the Robot-Oriented Design concept has also catalyzed many closed loop deconstruction systems such as Hat Down Method by Takenaka Corporation and Taisei's Ecological Reproduction System (TECOREP) (Bock and Linner, 2016a).

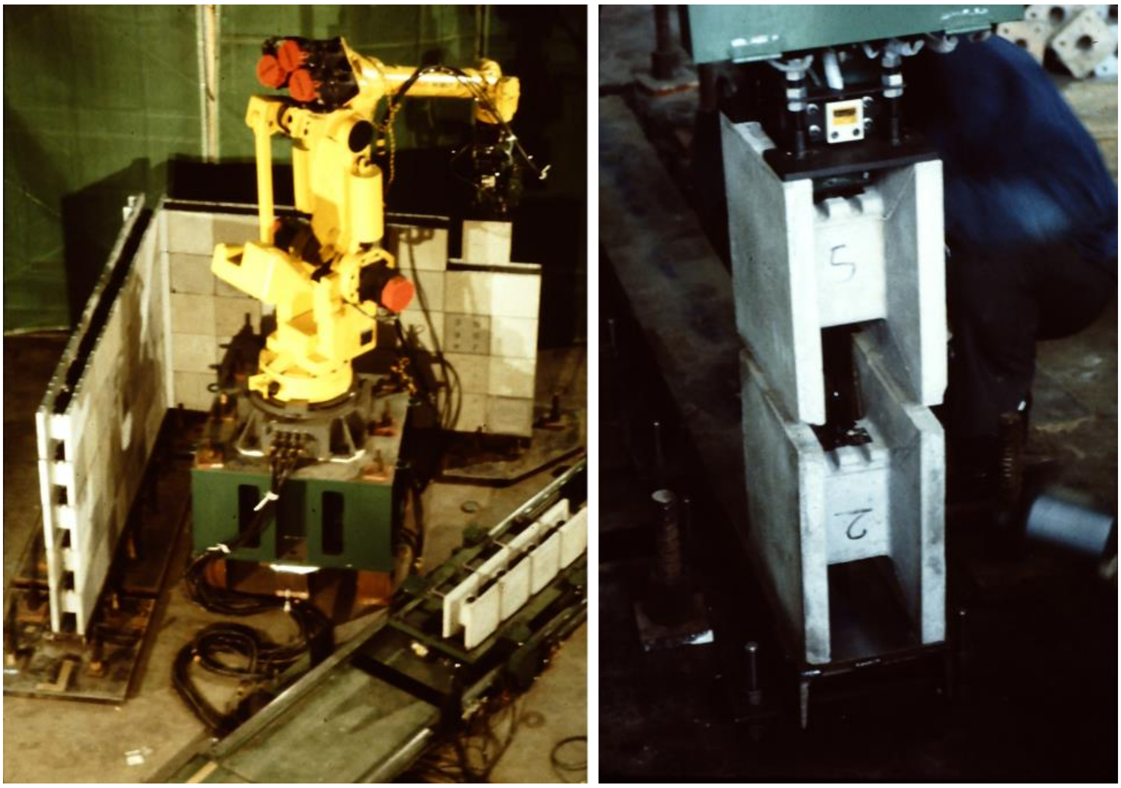

Figure 8 The SMAS robot developed for the assembly and disassembly of reinforced concrete blocks using Robot-Oriented Design concept (photo: T. Bock)

4. Case studies on the construction robots developed by University of Karlsruhe and Technical University of Munich

Today, the application areas of construction robots continue to expand. Recently, researchers have summarized some 200 existing construction robot systems into 24 categories based on their functions and features (Bock and Linner, 2016b). The following sections demonstrate the research endeavors led by the co-author T. Bock and his team to develop construction robots to promote circular construction at two German universities throughout the past few decades.

After the German reunification, there was an increased need for construction, especially for affordable housing - as is the case today. Together with SÜBA Bau AG, T. Bock developed the production system for the "x8 Haus" (see Figure 9) as part of his professorship for automation in construction operations at the civil engineering faculty of University of Karlsruhe (now Karlsruhe Institute of Technology) in 1990. It offered 100 m^2 of living space on two stories with a bathroom-toilet building service module, without a basement and can be prefabricated in 8 days by a specially developed multifunctional system with portal robots, assembled on site in 8 hours and sold for 80,000 German Marks (see Figure 10).

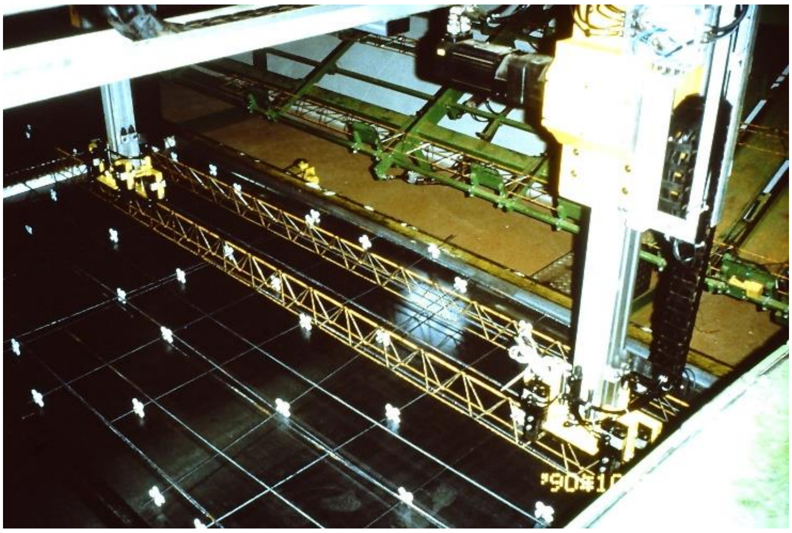

Figure 9 Robotic reinforced concrete parts production system for the “x8 Haus” (Photo: T. Bock)

Figure 10 The built “x8 Haus” applying the Robot-Oriented Design concept (Photo: T. Bock)

As mentioned above, construction robots are robots or automated devices that are developed primarily for tasks on the construction sites. It is a highly cross-disciplinary field which requires an integration of a variety of knowledge and expertise such as civil engineering, architecture, industrial design, construction management, robotics, mechanical engineering, electrical engineering, and informatics (Bock and Linner, 2016b). Over the years, the Chair of Building Realization and Robotics at Technical University of Munich together with its start-ups and spin-offs such as such as CREDO Robotics GmbH (https://credorobotics.com/), ARE23 GmbH (https://www.are23.com/), KEWAZO GmbH (https://www.kewazo.com/), ExlenTec Robotics GmbH (https://robotics.exlentec.com/) have vigorously contributed to the automation and robotization of construction especially regarding circular construction with several research and innovation projects. The following section will introduce three exemplary case studies on how Prof. Thomas Bock and his team contributed to the field of circular construction with construction robotics in recent years.

4.1 Case study 1: Consultancy on Investigating the Potential of Implementing Robotics and Automation in the Context of Large-scale Housing Development for Hong Kong

The public housing construction industry in Hong Kong, predominantly using prefabricated concrete as the construction material, faces conspicuous challenges of high demands, safety, an ageing workforce, inconsistent quality and stagnant productivity.

The consultancy project commissioned by the Construction Industry Council (CIC) of Hong Kong SAR evaluates the current on-site construction operation and identifies the existing bottlenecks that can be enhanced by implementing robotics and automation. In the current housing construction field, the systematic and scientific method to approach this type of undertaking, especially when closely associated with the industry and authorities, has not been comprehensively discussed.

Therefore, this project highlights the activities that signify these objectives, which include five key activities: literature review, industry survey, on-site case study, co-creation workshops and potential pilot project. As a result, a range of robotic applications that are tailor-made for Hong Kong's prefabricated public housing industry are recommended and hierarchically categorized. In addition, a semi-functional prototype of multifunctional façade-processing robot (e.g., painting, cleaning, grinding, inspection, marking, etc.) was designed, built and tested in laboratory as a proof of concept (see Figure 11 and Figure 12). The robot can work on the façade of high-rise public housing buildings in Hong Kong and beyond in collaboration with workers. In conclusion, the findings will inspire the construction industry to initiate and explore innovative, compatible as well as feasible solutions to the implementation of the robotic application in the future (Pan et al., 2018).

Figure 11 The multifunctional façade-processing robot showcasing the painting function on the façade of public housing buildings in Hong Kong (image: R. Hu)

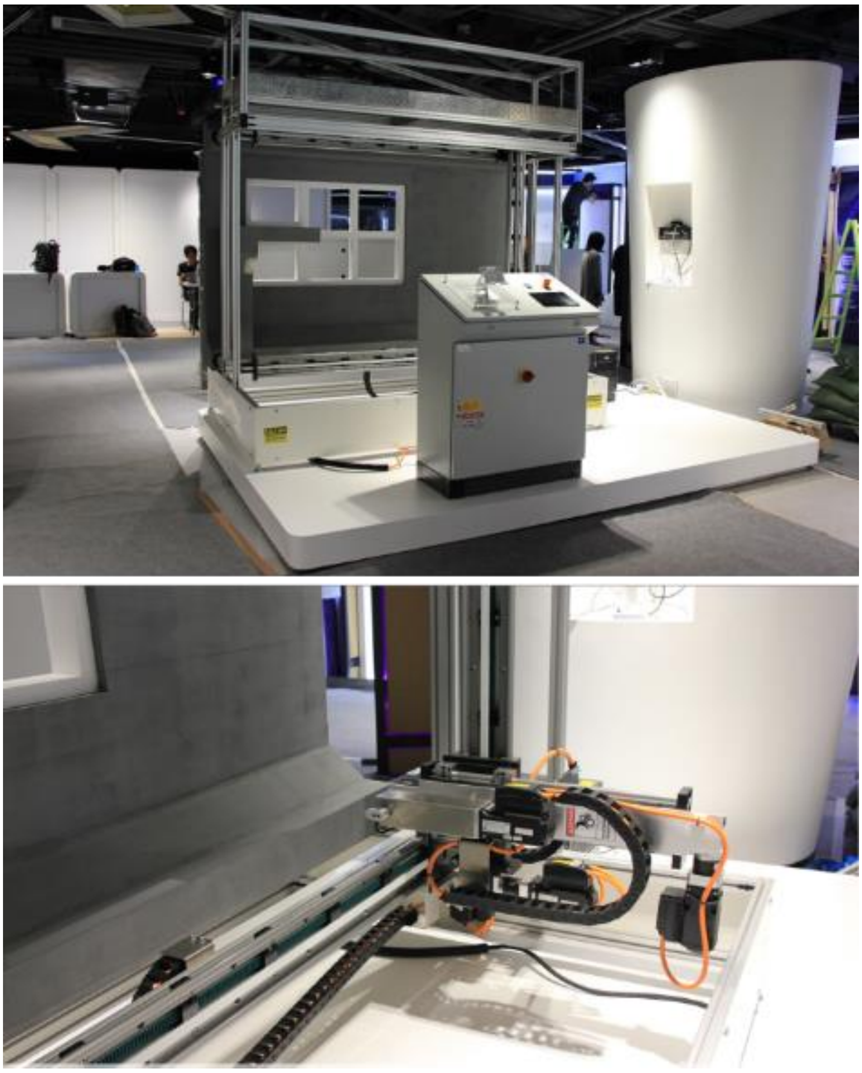

Figure 12 The semi-functional prototype of the multifunctional façade-processing robot displayed in the Construction Innovation and Technology Application Centre in Hong Kong (photo: R. Hu)

4.2 Case study 2: HEPHAESTUS cable-driven façade installation robot

HEPHAESTUS is short for Highly Automated Physical Achievements and Performances Using Cable Robots Unique Systems. The HEPHAESTUS project explores the innovative use of robots and autonomous systems in construction, a field where the incidence of such technologies is minor to non-existent. The project aims to increase market readiness and acceptance of key developments in cable robots and curtain walls. The installation of curtain wall modules (CWMs) is a risky activity carried out in the heights and often under unfavorable weather conditions. CWMs are heavy prefabricated walls that are lifted normally with bindings and cranes. High stability is needed while positioning in order not to damage the fragile CWMs. Moreover, this activity requires high precision while positioning brackets, the modules, and for that reason, intensive survey and marking are necessary. In order to avoid such inconveniences, there were experiences to install façade modules in automatic mode using robotic devices.

In HEPHAESTUS, a novel system has been developed in order to install CWMs automatically. The system consists of two sub-systems: a cable driven parallel robot (CDPR, see Figure 13) and a set of robotic tools named as Modular End Effector (MEE, see Figure 14). The platform of the CDPR hosts the MEE. This MEE performs the necessary tasks of installing the curtain wall modules. There are two main tasks that the CDPR and MEE need to achieve: first is the fixation of the brackets onto the concrete slab, and second is the picking and placing of the CWMs onto the brackets. The first integration of the aforementioned system was carried out in a controlled environment that resembled a building structure. The results of this first test show that there are minor deviations when positioning the CDPR platform (Iturralde et al., 2022). In future steps, the deviations will be compensated by the tools of the MEE and the installation of the CWM will be carried out with the required accuracy automatically.

Nevertheless, the initial on-site test results suggest that the robot can potentially boost productivity by 220% for an average construction job, compared to the conventional façade installation method. Furthermore, a study on the cost-benefit analysis of construction robots estimates that the HEPHAESTUS cable-driven robot for facade installation is theoretically worth investing in in the UK, as well as in the majority of G20 countries (Hu et al., 2021).

Figure 13 HEPHAESTUS cable-driven façade installation robot on a testing site (photo: T. Bock)

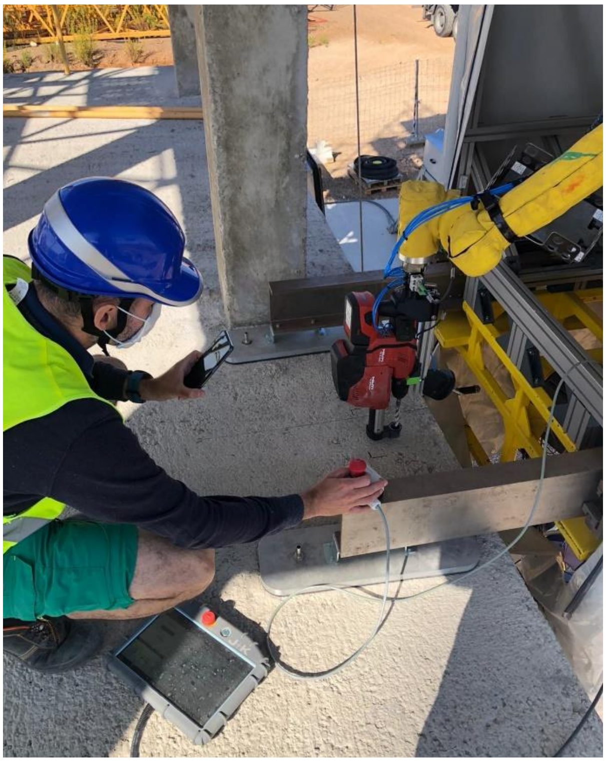

Figure 14 Checking the performance of the modular end-effector of the HEPHAESTUS robot (photo: S. Palencia Ludeña)

4.3 Case study 3: ARE23 wall painting robot

ARE23 GmbH was co-founded in 2020, and the CEO, Dr.-Ing. Wen Pan is a researcher at the Chair of Building Realization and Robotics. It is an augmented robotics engineering company whose mission is to support laborers in the construction space with artificial intelligence (AI) and robotics-driven technology. It automates the wall coating industry and digitalizes the entire operational process with affordable solutions. Its product range of small and large-scale spray coating robots used for residential and commercial-sized projects complements human skills, improves productivity and cuts costs.

Providing the workforce with a catalogue of robotic spraying solutions will allow the industry to satisfy the increasingly growing labor demand while guaranteeing premium paint application quality. A 3-axis machine for an interior surface coating robot that can autonomously scan a surface, determine its optimal path, and spray hard to reach surfaces. Leveraging Vention’s cloud-9 programming environment, they were able to write their own code and quickly merge it with their existing operating system (ARE-OS). ARE23’s specific combination of automation technology enabled by its advanced software platform will drive the digital transition in the construction coating industry. The start-up aims at developing a range of robotic solutions for the painting, plastering and coating of industrial spaces.

For example, the “TITAN” range (see Figure 15) is developed for larger commercial, and industrial applications, while the “COMPACT” range (see Figure 16) is suitable for residential, hotels, and offices. The initial test results suggest that both variants of the robot can potentially boost productivity by 250% compared to the conventional manual wall spraying method, with the same number of operators involved in both methods. The fully functional "COMPACT" product will be ready for the commercial pilot in early 2023.

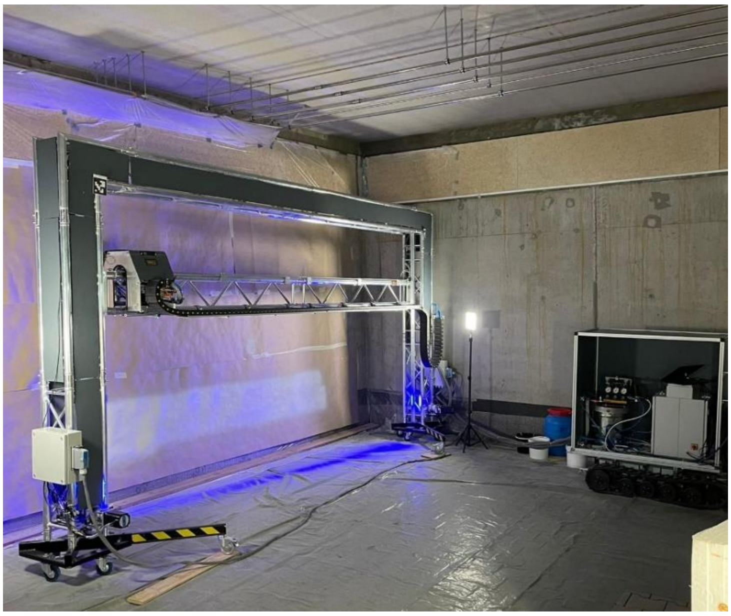

Figure 15 Prototype of the "TITAN" range on a pilot project site (photo: ARE23 GmbH)

Figure 16 Proof-of-concept prototype of the "COMPACT" range (photo: ARE23 GmbH)

5. Conclusion

In summary, the construction industry is a major consumer of natural resources. It is crucial to adopt the philosophy of circular economy into the construction sector. There are several existing regulations, guidelines, standards, certification frameworks, and subsidies on the EU and national levels to support circular construction in Germany. Innovative solutions such as construction robot and Robot-Oriented Design can potentially play a significant role in the sustainable development of the construction industry by improving productivity, reducing waste, enhancing safety, as well as mitigating labor shortages. The research and innovation endeavors represented by several research projects and entrepreneur activities conducted by the Chair of Building Realization and Robotics at Technical University of Munich along with its in-house spin-offs and start-ups such as CREDO Robotics GmbH, ARE23 GmbH, KEWAZO GmbH, ExlenTec Robotics GmbH over the years contributed significantly to the knowledge and know-hows in the construction industry, especially for circular construction.

In connection with new approaches from the field of human-centric use of robots, human labor can be perfectly supplemented in order to compensate for the shortage of skilled workers. Automated construction machinery for infrastructure construction offers highly efficient solutions for the expansion and renovation of roads, railroads, bridges, and tunnels. Advances in the field of digital connection and programming of robots increasingly facilitate the use of these solutions. Future research will be conducted on the universal simulation environment for customized robotic applications for a resource-efficient and human-centric construction industry. Furthermore, the knowledge and know-hows gained in these endeavors will lay the groundwork for the next frontier of construction robotics beyond the construction sites, such as dismantling modular buildings and infrastructure (Figure 17) and constructing space architecture (Figure 18).

Figure 17 Concrete dismantling and recycling robot Garapagos (Photo: T. Bock)

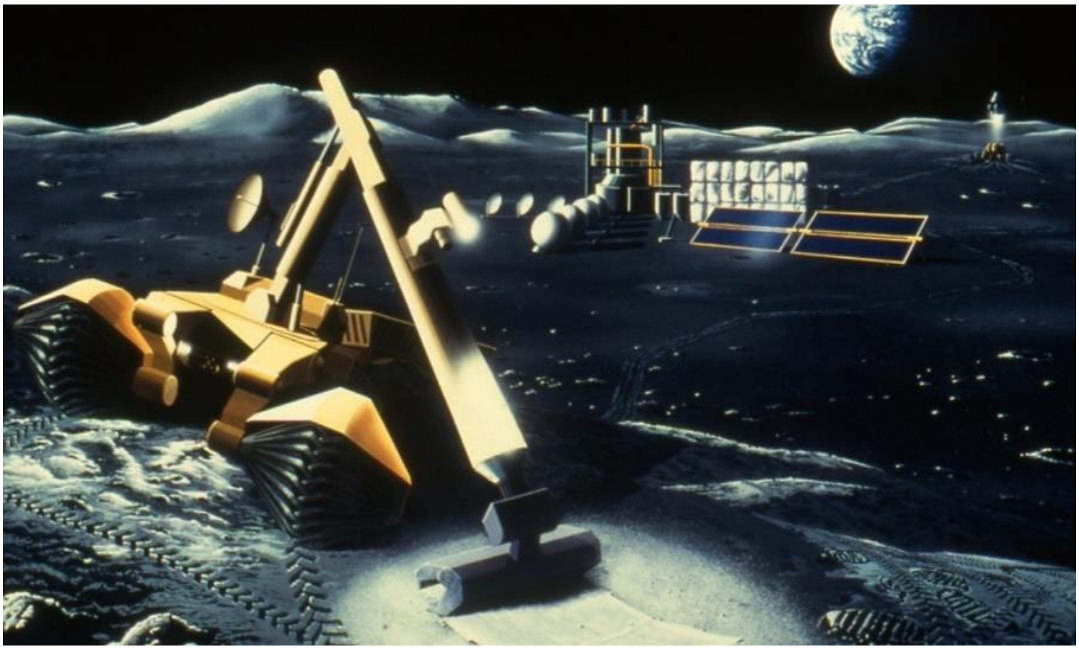

Figure 18 Next frontier for construction robotics: space stations and colonies (Photo: T. Bock)

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Circular Economy Policies in the European Framework: a Focus on the Construction Sector

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Abstract

Resource scarcity and climate change are two of the biggest challenges of our times. The concentration of greenhouse gas is rising steadily since the Industrial Revolution, leading to an average global temperature that is higher and higher and we are consuming resources for 1.75 planet. The construction sector is one of the main responsible of the emissions and therefore is object of great attention from policy makers and academia aiming at finding innovative solutions to cut emission of this sector that, alone, is responsible of the 40% of greenhouse gas emissions. In addition, the construction and demolition waste accounts for the 35.9% of the total waste, representing the largest category. Circular economy is seen as an opportunity to thrive and tackle climate change, fostering a new model of economy that overcomes the linear process of "take-make-dispose", which is the basis of the current economic system. Indeed, circular economy aims at implementing thriving systems without continuing with the consumption of the finite resources, but eliminating the concept of waste and pollution, maintaining products and materials in loop at their highest value and regenerating nature. Circular economy principles have been applied to the construction sector, trying to overcome the focus on energy efficiency of building and widening the perspective to embrace the whole life cycle in the discourse. However, an holistic vision is still missing.

The purpose of this contribution is to explore and present the policies related to the circular economy at European level, starting from the first circular economy action plan enacted in 2015 and going towards the current European Green Deal and the new circular economy action plan. Through the implementation of the first action plan, many interesting results have been achieved, such as the first monitoring system available at EU level and the European Circular Economy Stakeholder Platform, a collaborative network of stakeholders. In addition, the partnership on Circular Economy of the Urban Agenda has developed a framework for cities to implement actions and integrate circular economy principles pursuing the objectives of better regulations, better knowledge and better funding. Moving from a strategic to a regulative framework, a European directive does not exists targeting the construction sector since the building stock and the climate conditions vary significantly across EU. However, the Level(s) framework has been developed and tested, representing a common EU framework of core sustainability indicators for office and residential buildings. Level(s) framework inspired already many regulations that are in force in some Member States, and the Italian case of the minimum environmental criteria is presented. Lastly, the manuscript presents the circular building toolkit, as an interesting case study for the implementation of the circular economy principles to the construction sector.

Keywords: Circular economy, Construction sector, Europe.

1. Circular economy, an introduction

Resource scarcity and climate change are two of the biggest challenges of our times. At present, we need 1.75 planets (https://data.footprintnetwork.org) to provide the necessary resources and capacity to absorb our waste, with the consequence that the overshoot day is being anticipating every year: in about 7 months all the resources that the planet is able to regenerate for the entire year have already been consumed by the humankind. Projecting this trend in 2030, we will need more than two planets (Global Footprint Network, 2023). In addition, industrialization, deforestation and large-scale agriculture have been growing exponentially in the last one century and a half; as a consequence, never seen quantities of greenhouse gases (GHGs) have been released in the atmosphere (United Nations website). Scientifically, it has been established that the concentration of GHGs in the Earth's atmosphere is directly linked to the average global temperature on Earth. This concentration has been rising steadily, leading to a higher and higher mean global temperature, since the time of the Industrial Revolution. The most abundant GHG is the carbon dioxide (CO_2) that accounts for about two-thirds of GHGs. It is largely the product of burning fossil fuels.

Within the resourceful cities network, cities are considered *"big enough to make a difference but small enough to make it happen"* (Resourceful Cities Network, 2022). Indeed, cities drive the consumption of natural resources being responsible for a percentage of more than 60% (OECD, 2010), they produce from 60% to 80% of greenhouse gas emission (UNEP, 2016) and 50% of global waste (OECD, 2020). However, cities are places of innovation and where there is the greatest potential for changing, especially considering that the 66% of world population is expected to live in urban areas within 2050 (UN DESA, 2019).

The construction sector is one of the main responsible of the emissions and consequently it is object of great interest from researchers and policy-makers aiming at finding new innovative solutions to cut emissions, specifically when it comes to building conservation and renovation (Sáez-de-Guinoa et al., 2022). In fact, constructions are impacting on both the sides of resource consumption and waste production: it is estimated that construction materials like cement and iron, together with industrial process for the construction industry, are responsible for the 40% of GHGs emissions (European Construction Sector Observatory, 2019), while the construction and demolition waste (CDW) represents the largest category produced in Europe in 2018 accounting for 35.9% of the total waste (Eurostat, 2021).

Circular Economy is an opportunity to face resource scarcity, offering an alternative to the linear model of consumption and production based on the "take-make-dispose" process, towards a circular model in which resources are looped and kept in the system as long as possible and at their highest value. In addition, in April 2022 it has been mentioned for the first time that Circular Economy is a solution to tackle climate change, due to its application to many sectors of economy (IPCC, 2022). As a consequence of this extreme flexibility of the concept, a clear and unique definition does not exist (Kirchherr et al., 2017). The Ellen Mac Arthur Foundation (EMF) is a pioneer in the field. Founded in 2010 by Ellen Mac Arthur, today the association is one of the biggest entity recognized at international level promoting the concepts of the circular economy and the sustainable transitions[1]. The first report drafted titled "Towards the circular economy" was disrupting since for the first time the validity of the concept has been demonstrated, both in terms of strategic opportunities that will raise and in terms of economic benefits. The report asserts that the transition towards the circular economy is economically viable and scalable for different products and it demonstrates the advantages for both companies and consumers (Ellen Mac Arthur Foundation, 2013). According to the Foundation, the circular economy is a "*systems solution framework that tackles global challenges like climate change, biodiversity loss, waste, and pollution. It is based on three principles, driven by design: eliminate waste and pollution, circulate products and materials (at their highest value), and regenerate nature*" (Ellen Mac Arthur Foundation website). It is considered as a new type of economy that overcomes the actual "take-make-dispose" model based on the (uncontrolled) consumption of natural resources. It is estimated that the transition towards the use of renewable resources can address the 55% of global GHGs emissions, but in order to reach the climate neutrality it is necessary to tackle the remaining 45% that are related to the way products are made and used. It has been also demonstrated that designing out waste, keeping materials in use, and regenerating farmland can reduce emissions by 9.3 billion tons. It is equivalent to eliminating current emissions from all forms of transport globally (Ellen MacArthur Foundation, 2019). For Europe, adopting a circular economy pathway could halve the carbon dioxide emissions by 2030 compared to the actual levels within mobility, food system and built environment.

Starting from the "closed loop economy" (Stahel et al., 1981) and the "Cradle-to-Cradle" (C2C) model theorized by Braungart and McDonough (2010) , the EMF theorized the "butterfly model" (Ellen Mac Arthur Foundation et. al., 2015) in which the Foundation aimed at capturing the essence of circular economy taking into consideration several input from the various schools of thoughts, event thought the two material cycles of the C2C is the most recognizable. The butterfly diagram is shown in Figure 1 and explains how the flows of both biological and technological materials can be closed maintaining products and resources at their highest value, through regeneration, repair, reuse, refurbish, and only lastly recycle.

[1] https://ellenmacarthurfoundation.org/network/overview

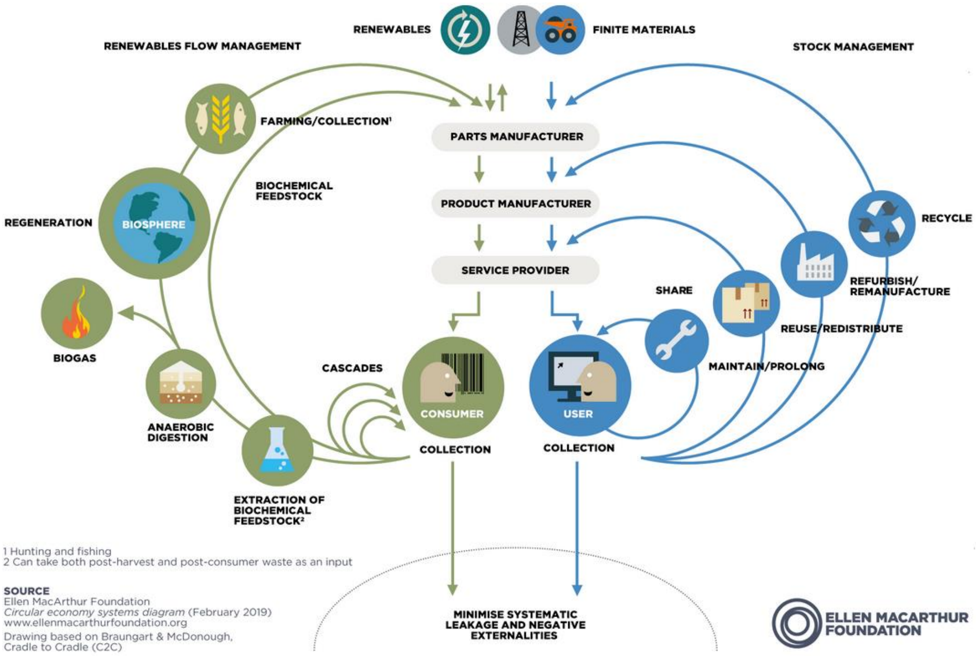

Figure 1 The butterfly model as conceptualized by Ellen Mac Arthur Foundation

2. Circular economy policies in Europe

2.1 Policy framework

As far as circular economy in Europe is concerned, the reference policy document is the New Circular Economy Action Plan. It has been adopted by the commission in March 2020, as one of the main pillar of the European Green Deal which is considered the EU agenda for sustainable growth. However, as its name predicts, it is rooted in previous initiatives promoted by the European Commission, starting from 2015 when the first circular economy action plan was adopted. This initial plan included measures stimulating the Europe's transition towards a circular economy while fostering sustainable economic growth and the generation of new jobs. 54 actions were included in the plan, and after three years of implementation, all of them have been achieved even if for some actions the work continues also beyond 2019. Actions were related to the whole life cycle going in detail of different phases of the production and consumption process. The actions are divided according to the topic they mainly refer to: production, consumption, waste management, market for secondary raw materials and sectorial actions concerning some on strategic sectors (e.g. plastic, food waste, critical raw materials, construction and demolition, biomass and bio-based materials, innovation and investments, monitoring). A comprehensive report has been drafted by the European Commission and released on 4th March 2019 with the aim to present the main achievements and the open challenges of the transition towards a circular economy and climate neutrality. In this report it is stated that in 2016 the employment rate in circular jobs increased of 6% compared to 2012 and circular activities such as repair, reuse or recycling generated almost €147 billion in added value requiring around €17.5 billion of investments.

The most important results coming from the implementation of these actions constituted the milestones towards the adoption of the European Green Deal and the New Circular Economy Action plan. In this respect, when it comes to the production processes and the circular design, in November 2016 the Eco-design working plan 2016-2019 has been issued, with the purpose of identifying Commissions' priorities under eco-design and energy labelling. In Europe, both Eco-design and Energy labelling Directive are framework directives and therefore they should be transposed by Member States which set out binding requirement specific for each product group. Working plans have the purpose of identifying categories of products to be investigated in the next three coming years to be analysed in depth and for which new measures can be prepared. Eco-design directive and Energy Labelling measures have been then modified including new material efficiency requirements such as ease of repair and the facilitation of the end-of-life treatment. Beyond these mandatory aspects, voluntary tools have been developed such as the EU Ecolabel and the Green Public Procurement criteria. In October 2019, 10 Eco-design implementing regulations have been adopted especially concerning household appliances like refrigerators, washing machines, dishwashers and televisions.

Another milestone towards the adoption of the European Green Deal is represented by the adoption of the **circular economy package in January 2018**. As part of this package, the development of a new monitoring system for the circular economy is important to highlight. In fact, it responds to the necessity of measuring the transition in a clear and possibly commonly-defined way, being difficult universally to frame the "circularity" phenomenon. Moreover, with a unique score or a single index it is impossible to capture the extreme complexity of the transition towards circularity; the proposed monitoring system includes 10 indicators covering the different phases life cycle of products and competitiveness aspects. The use of these indicators in not mandatory for the Member States, however some of them have developed additional indicators completing the picture depicted by the European Commission. The complete list is reported in Table 1.

Table 1 Proposed indicators for Circular Economy monitoring in EU

Category	Indicators	Notes
Production and consumption	1) Self-sufficiency of raw materials for production in EU	
	2) Green Public Procurement	Financing aspects
	3) Waste generation	Consumption aspects
	4) Food waste	
Waste management	5) Recycling rates	Share of recycled waste
	6) Specific waste streams	Packaging, biowaste, etc.
Secondary raw materials	7) Contribution of recycled materials to raw materials demand	
	8) Trade of recyclable raw materials between the EU Member States and with the rest of the world	
Competitiveness and innovation	9) Private investments, jobs and gross value added	
	10) Patents related to recycling and secondary raw materials as a proxy for innovation	

The indicator framework is able to capture the changing occurring in the priority areas for the European Commission and it is able to assess whether measures put in place are effective. It is published on a website[2] and some indicators are calculated through a sum of more than one sub-indicator. At the time of its release (2018) some first findings have been displayed and are reported in the following. Progresses are observed in the field of production and consumption, given the trend of the waste generation indicator. However, Europe is largely dependent on import when it comes to the critical raw materials. In addition, public procurement accounted for a large percentage of the GDP and hence the adoption of green criteria for public procurement in the member states is considered a driver for circular economy transition to be monitored. When it comes to the waste management, the trend is positive since EU recycling rate is increasing as the recycling rates for packaging waste. As far as construction and demolition waste is concerned, the recycling rate is more than 70%. However, it includes backfilling which is not keeping the values of materials in the economy and therefore it is not expression of a transition towards the circular economy. In addition, member states report results in a very different ways and this invalidate both the comparison and the robustness of the indicator. Considering the use of secondary raw materials, the contribution to the materials demand is very low (only around 10%). Lastly, indicators in the competitiveness and innovation category aims at monitoring the increased investments on circular economy, the creation of new jobs together and progresses in innovation. This latter is monitored through the number of patents on recycling and secondary raw materials and the data acquired show an increase of 35% between 2000 and 2013.

As part of the circular economy package, a Europe-wide strategy for plastics in the circular economy and a report on critical raw materials and the circular economy are also mentioned as key fact.

In the same year (July 2018) the revised legislative framework on waste has entered into force and it is mandatory for the Member States to adopt legislations according to the new target and objectives stated by the EU. Among others, new ambitious yet realistic recycling rates are defined requiring that by 2030, 70% of all packaging waste should be recycled as well as the 65% of municipal waste by 2035. In addition, landfilling of municipal waste should be reduced and maintained up to 10% of municipal waste.

As mentioned before, in the circular economy action plan the consumption practices and the investments in innovation are also present. Concerning the first one, EU states that the transition towards a circular economy is not possible without the active engagement of citizens in changing their consumption patterns. In order to shift purchasing towards more sustainable choices, two methods for the identification of environmental performance of products have been conceived: the Product Environmental Footprint (PEF) and the Organisation Environmental Footprint (OEF). Lastly, it is worth to mention the efforts made by the European Commission in investing in innovation and supporting the adaptation of the industrial sector base, with more than €10 billion in public funding for the transitions. Together with this initiative, the Commission also addressed regulatory obstacles that may hinder circular innovation. Stakeholders engagement is also crucial for the transition to

[2] https://ec.europa.eu/eurostat/web/circular-economy/indicators

happen and, in this framework, industry engagement has led to the adoption of Construction and Demolition Waste Protocol and Guidelines with the aim to increase confidence in waste management and in the quality of recycled materials in the construction sector.

Thanks to the implementation of the 54 actions, the EU is recognised as a leader in circular economy policy-making globally, and the action plan encouraged at least 14 Member States, 8 regions and 11 cities to put forward circular economy strategies. (EMF website https://ellenmacarthurfoundation.org/circular-examples/the-eus-circular-economy-action-plan).

As said before, all the 54 actions included in the first circular economy action plan has been completed within 2019 and, in December of the same year, the European commission adopted the **European Green Deal**. It consists in a package of policy initiatives set up to paving the road for a green transition, with the ultimate goal of reaching climate neutrality by 2050. The European Green Deal will transform EU into a modern and competitive system, decoupling economic growth from the use of finite resources and ensuring a fair and prosperous society with no person and no place left behind.

The green deal aims to achieve these three main goals. First, it focuses on achieving net-zero emissions by 2050 proposing specific strategies that can help curb emissions across all sectors, with a strong focus on energy. The objective is to increase the share of renewable energy in the EU's energy mix. Second, it plans to decouple growth from resource exploitation: while reductions in emissions have been achieved in the last decade, Europe remains one of the major contributors of resource consumption in the world. Described as a "generation-defining task," achieving this objective will not only require a boost in technological advancements but also rethinking lifestyles, communities, and societies. Third, there is the need to foster an inclusive green transition and to leave none behind, supported through the Just Transition Mechanism, which will provide between 65€ and 75€ billion over the period of 2021-2027 to alleviate the socio-economic impacts of the transition. As intermediate goal, the package of initiatives and the investments are aimed at reducing at least 55% net GHGs emissions by 2030, compared to 1990 levels.

As one of the main pillar of the European Green Deal, in March 2020, the European Commission adopted the **New Circular Economy Action Plan**[3]. The Commission announced that the transition to a circular economy will reduce pressure on natural resources and will create sustainable growth and jobs, but, of utmost importance, it is also considered a prerequisite to achieve the EU's 2050 climate neutrality target and to halt biodiversity loss.

The new action plan is composed of 35 action to be implemented in the timeframe 2020-2023 focusing in different areas in respect to the previous action plan. In fact, the key actions are listed under seven macro-areas that correspond to as many overall goals and targets: a sustainable product policy framework, key product value chains, less waste more value, making the circular economy works for people, regions and cities, crosscutting actions, leading efforts at global level, monitoring the progress. Within the design of sustainable products, the idea is to broaden the Eco-design directive beyond energy-related products improving product durability, reusability, upgradability and

[3] https://environment.ec.europa.eu/strategy/circular-economy-action-plan_en

reparability, increasing the recycled content. Priority areas of interventions are electronics, textiles and ICT. Among the key product value chains, it is worth mention for the scope of the present research the construction and building category. In the Action Plan, the Commission proposes to launch a new comprehensive strategy for a Sustainable Built Environment aiming at coordinate and ensure coherence climate goals, energy and resource efficiency, construction and demolition waste, accessibility, digitalization and necessary skills. In detail, the strategy should promote circularity principles through the revision of the construction product regulation, promoting the adaptability of the built environment, using Level(s) tool (see paragraph 3.2 for more details) to integrate life cycle assessment in public procurement, revisioning the legislation for construction and demolition waste and promoting initiatives to reduce soil sealing fostering the reuse of abandoned sites and contaminated brownfields. The strategy for a Sustainable Built Environment is still not published in the EU framework, even though it was expected in 2021. However, some of the actions have been addressed in the "Renovation Wave for Europe"[4] in which particular attention has been paid to greening buildings.

In the three years passed from the adoption of the circular economy action plan, many results have been achieved. The Commission adopted a proposal for a new regulation on sustainable batteries (2020), a Global Alliance on Circular Economy and Resource Efficiency (GACERE) has been launched in 2021 and new proposals about organic pollutants in wase and waste shipments are adopted. In March 2022 the European Commission adopted a package of measures proposed in the circular economy action plan consisting in sustainable products initiative (including a proposal for Eco-design for sustainable products regulations), the EU strategy for circular textiles, a proposal for a revised construction products regulation and a proposal for empowering consumers in the green transitions. As far as the construction products regulation is concerned0, some other measures have been adopted in November 2022 with the revision of the EU rules on packaging and packaging waste and a communication on a policy framework for bio-based, biodegradable and compostable plastics.

2.1.1 A collaborative platform for the EU

The importance of stakeholders engagement for the achievement of the circular economy goals and the climate neutrality has been highlighted in many of the documents mentioned in the paragraph above, starting from the very beginning with the first circular economy action plan. As part of its implementation, the **European Circular Economy Stakeholder Platform**[5] has been created. The platform is a joint initiative by the European Commission and European Economic and Social Committee and consists of a web-space to collect and promote good practices about Circular Economy. It is a showcase of what Europe has to offer in the field of circular economy and represents an opportunity for networking among public administrations or European entrepreneurs. It is a "network of network" aiming at driving the circular economy in the Member State from regional and local governments to the civil society, strengthening the cooperation among stakeholders and identifying

[4] https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1603122220757&uri=CELEX:52020DC0662

[5] https://circulareconomy.europa.eu/platform/en

social, cultural and economic barriers for the transition, informing policies at various level of governance. The platform is articulated into 3 pillars: the knowledge hub, the toolbox and exchange section. The knowledge hub represents a searchable database in which good practices, innovative processes and learning experience are submitted by stakeholders and made available to the public. Strategies adopted at national or local level by public authorities for a transition towards circular economy are also included in the database together with relevant studies and reports published on the topic. Good practices, strategies, European networks and events are also georeferenced and made available through a map view (**Figure 2**).

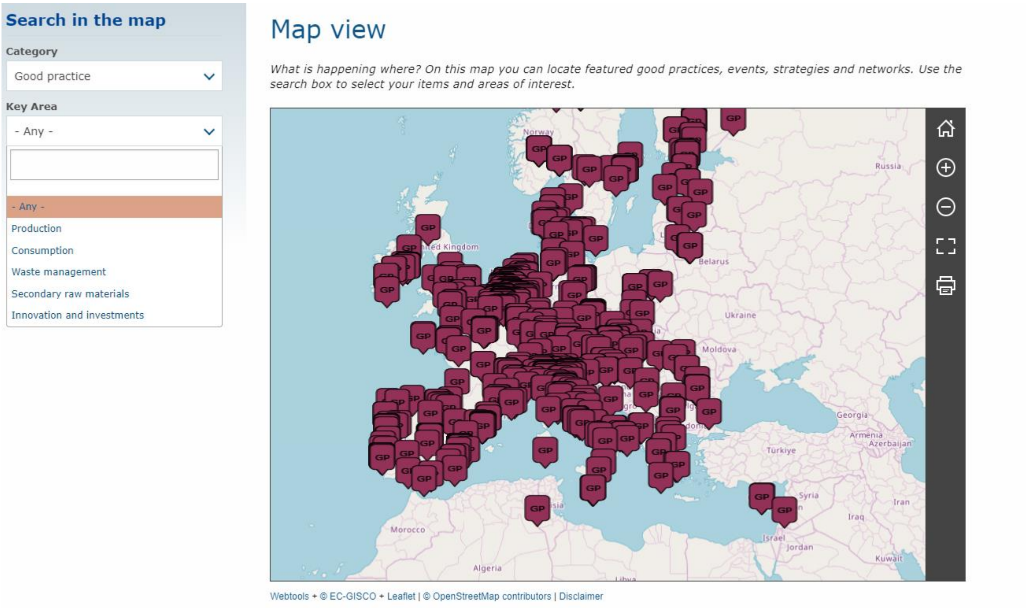

Figure 2 Excerpt of the ECESP platform. The knowledge hub with the good practices collection

The toolbox deals with education and financial aspects by providing relevant examples of educations, innovative processes submitted by stakeholders and also new opportunities and advices for financial support for the development of circular economy initiatives. A specific section is also dedicated to financial support by EU institutions, the European Investment Bank and other entities at various level. Lastly, the platform also represents the possibility for stakeholders to interact through European networks and contacts, activities and Circular Talks; these latter are a series of online workshops, webinars and interviews with experts of circular economy, enhancing the possibility of exchange and sharing of good initiatives.

2.1.2 The Urban Agenda Partnership on Circular Economy

Another relevant initiative is Europe is the Urban Agenda for the EU. It is a partnership that brings together cities, members states and European institutions with the aim to ensure that the strategies of the New Urban Agenda and the UN Agenda 2030 are acknowledged in the EU legislation, EU funding and knowledge sharing. The Urban Agenda is structured in **14 priorities themes** for the sustainable development of cities; among those one there is the **partnership on Circular Economy**. The aim of this partnership is to increase the interest of circular economy principles into cities and to foster the re-use, repair, refurbishment and recycling of materials and products. Even though the circular economy concept is considering the whole cycle of production process, from the raw materials to the treatment of waste, the partnership focuses on those aspects that have greatest potential in cities and can create the biggest opportunities. The work started in 2017 and the final report about the initiative has been issued in April 2021 (Urban Agenda for the EU, 2021) collecting all the output achieved by the partnership and focusing on a series of actions and recommendation to provide advices and strategies for cities towards the circular economy. The actions are divided into three category: Better Regulation, Better Funding and Better Knowledge. In the figure below is it possible to see the catalogue of the 12 actions proposed.

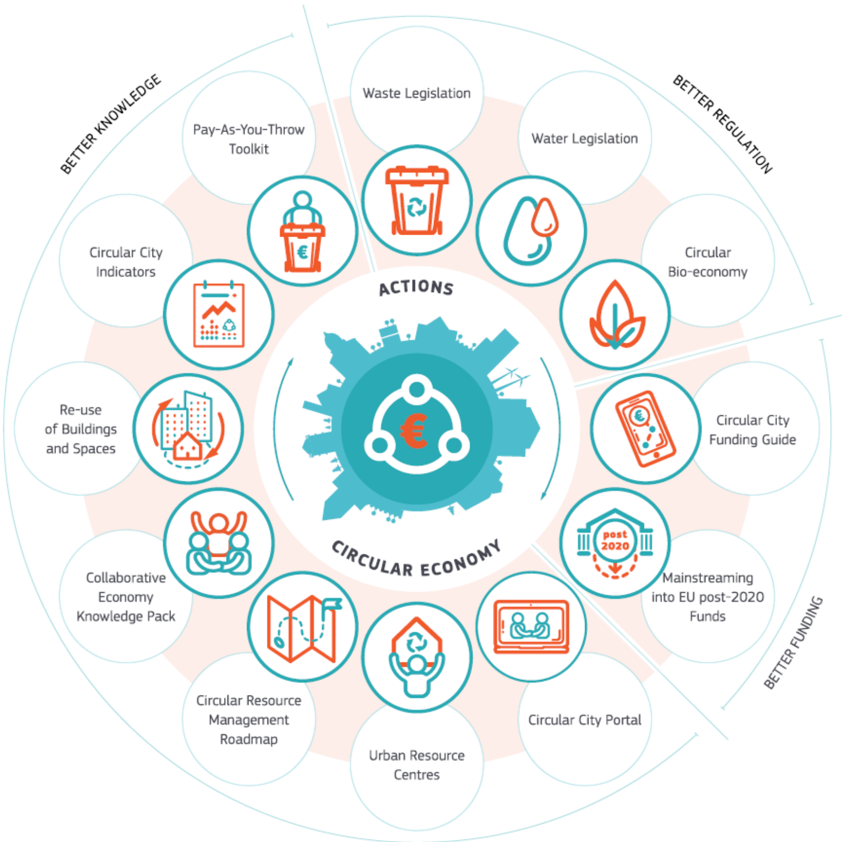

Figure 3 Summary of the actions proposed by the circular economy partnership
Source: Urban Agenda for the EU on Circular Economy, final report (2021)

When it comes to the **better regulation** category, three main areas have been touched: waste, water and bio-resource legislations. Starting from the analysis of barriers in the actual legislation, the partnership provides proposals of changing the articles of the legislations, however many of them are designed and suitable for the take-make-disposal economy and therefore non optimal for the circular economy. A booklet for better regulation, surveys and a position paper have been produced in this framework.

Dealing with **better funding** category, the report highlights that the transition to a circular economy require funds. It is therefore important that cities are aware of the different possibilities available when it comes to funding sources for the development of circular initiatives. This goal, together with ensuring that the EU funding acknowledges the need for circular funding , is at the basis of the two actions proposed in this category. The circular city funding guide is a website[6] developed in this context with the aim to improve access to funding for circular projects and companies in cities.

When it comes to the **better knowledge** category, it is possible to see that the majority of the actions belong to this topic. During the working timeframe, the partnership identified many barriers (around 30) and the actions are designed to address 7 of them, trying to reduce the big knowledge gap that is currently present. For the scope of the present research, it is interesting to mention the handbook for Sustainable and circular re-use of buildings (Urban Agenda for EU, 2021) and the collaborative economy knowledge pack for cities. The latter is a powerful tool to underline not only the environmental and economic challenges of the linear model of consumption, but also the importance of the social and democratic dimension of the transition towards the circular economy. The package includes drivers, barriers and tools (e.g. carsharing, sharing of clothes, repair cafes and food cooperatives) to foster the collaborative economy in cities and regions. Regarding the handbook for the sustainable and circular re-use of buildings and spaces, it is conceived together with the Partnership on Sustainable use of land and nature-based solutions proposing solutions for the increasingly relevant theme of the re-use of abandoned or underused building and spaces. The tool is considered a starting point for the development of a new strategy focused on new urban model for the re-use of buildings in the cities according to a circular perspective.

2.2 International Standards

International standards related to circular economy are still under development by ISO/TC 323 Secretariat. The following areas will be covered:

1) ISO/CD 59004 - Circular Economy – Terminology, Principles and Guidance for Implementation https://www.iso.org/standard/80648.html?browse=tc
2) ISO/CD 59010 - Circular Economy — Guidance on the transition of business models and value networks https://www.iso.org/standard/80649.html
3) ISO/CD 59020 - Circular Economy — Circular Economy — Measuring and assessing circularity https://www.iso.org/standard/80650.html?browse=tc
4) ISO/CD TR 59031 - Circular economy – Performance-based approach – Analysis of cases studies https://www.iso.org/standard/81183.html?browse=tc
5) ISO/CD TR 59032.2 - Circular economy – Review of business model implementation https://www.iso.org/standard/83044.html?browse=tc
6) ISO/WD 59040 - Circular economy – Product Circularity Data Sheet https://www.iso.org/standard/82339.html?browse=tc

[6] https://www.circularcityfundingguide.eu/

3. The circular economy in the construction sector

As mentioned in the previous paragraph, the European Commission was supposed to publish a strategy for Sustainable Built Environment in 2021. Even though the report has not been issued yet, the Commission still see the necessity of addressing this topic in a comprehensive and holistic way. In fact, more than 220 million buildings in Europe have been built before 2001, representing 85% of the EU's building stock. It means that between the 85 and 95% of the buildings that exists today will still be standing in 2050. It is though clear that, in order to achieve the climate neutrality by 2050, there is the necessity to deal with existing assets renovation and transformation towards circular buildings, and not only focus on the realization of new ones. Most of those existing buildings are not energy-efficient and many rely on fossil fuels for heating and cooling, using also old technologies and wasteful appliances (European Commission, 2020). Currently, the renovation rate of buildings is 1%, but 3% is the supposed rate by the EU to reach energy efficiency and the climate target that the European Commission is setting (Sáez-de-Guinoa et al. 2022).

Many scholars are applying the circular economy principles to the built environment. According to Munaro et al, (2020) the most covered topics by the academic discourse are: the recyclability and re-use of material, especially aiming at collecting best practices for construction and demolition waste management in the value chain, waste reuse and recycled aggregates; the circular transition related to the development of sustainable services and production systems with the introduction of the concept of the adaptive reuse; the use of new tools for the assessment to support circularity in buildings like the development of circular indexes, deconstruction processes, the use of BIM, the introduction of material passport; Life Cycle Analysis (LCA) and Life Cycle Costing (LCC) as methodologies for the evaluation of the environmental performance; the role of the design of products and buildings; the analysis of the material stock and flow in buildings introducing the concept of urban mining (Munaro et al, 2020). A CE framework for buildings is proposed by Sáez-de-Guinoa et al. (2022) including the main circular strategies applied to the construction value chain.

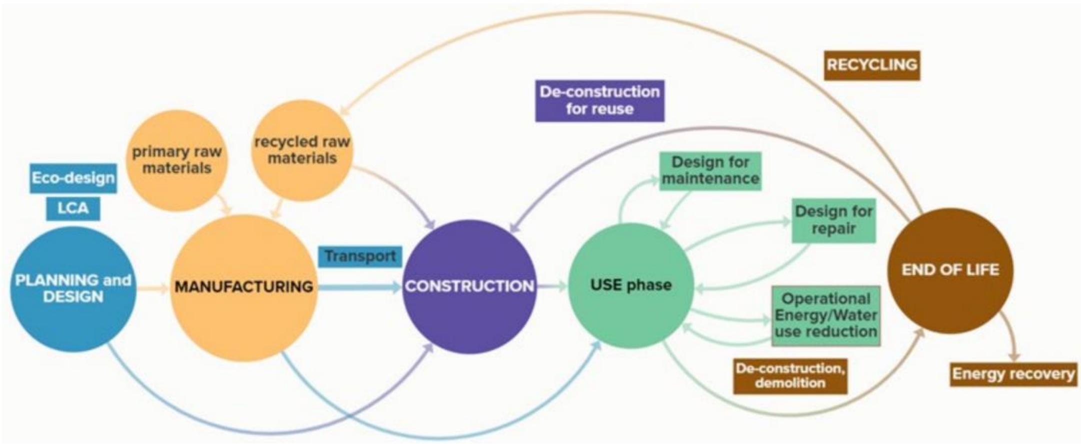

Figure 4 Circular strategies applied to the construction framework (in Sáez-de-Guinoa et al. (2022))

Notwithstanding the many axis of analysis, cultural, regulatory, financial and also sectorial barriers have been highlighted (Hart et al., 2019) towards the application of the circular economy principles to the built environment, underlying the complexity of the approach and the difficulties of translating the theory into practice. Amon others, the lack of an homogeneous regulatory framework addressing the challenge in an holistic way and the lack of interest, knowledge, skills and engagement throughout the value chain are mentioned.

The **ReSOLVE framework** developed by EMF (Ellen Mac Arthur, 2015). is considered as one of the most effective and comprehensive framework for the transition from the linear to the circular economy (Lewandowsky, 2016). Some scholars tried to applied the framework to the building sector, giving concrete examples of the actions and principles to undertake cataloguing them among the 6 actions of the framework: Regenerating, Sharing, Optimizing, Looping, Virtualizing and Exchanging (Huovila et al., 2019; Geissdoerfer et al., 2020; Norouzi at al., 2021; González et al., 2021). Regeneration in the building sector can be seen in the practices of substitution of the finite resources to the use of renewable energy and materials, reducing the consumption of raw materials and waste generation; Sharing is the possibility for a building to maximize its utilization, increasing cooperation among all the actors and prolong the life span through maintenance, repair and reuse practices. Modular construction and design for disassembly are some examples. Optimize is the necessity of improving the performance and efficiency of buildings, eliminating wastes and reducing the use of primary materials. All the components may be reused or repurposed. Supporting the development of mixed-used buildings and adaptable space configurations, integrating smart devices, fostering the design of passive buildings are few examples. Looping is again referring to the concept of maintaining components and materials in use and in closed loop within the value chain, prioritizing the approach of modular construction and engaging stakeholders and manufactures for the support of materials recovery incentivizing reuse instead of recycling. When it comes to Virtualize, the action can be interpreted as the use of smart technology for facilitating the maintenance tasks, the use of BIM throughout the whole life-cycle of buildings (from design to the operation and end-of-life phase) and the creation of material banks. Lastly, Exchange is based on the promotion of the concept of being users instead of owners thus fostering the creation of new business model of leasing, but also the replacement of finite resources with renewable energy ad materials.

As mentioned, circular economy principles should be taken into account both in the analysis of building renovation and the construction of new buildings and, moreover, taking into consideration all life cycle stages. According to circular design of buildings, developed by Metabolic, the city of Amsterdam an Copper8, the circular construction is summarized in 8 principles, with the reference indicators, as it is possible to see in **Figure 5:** circular construction in 8 principles**Figure 5**.

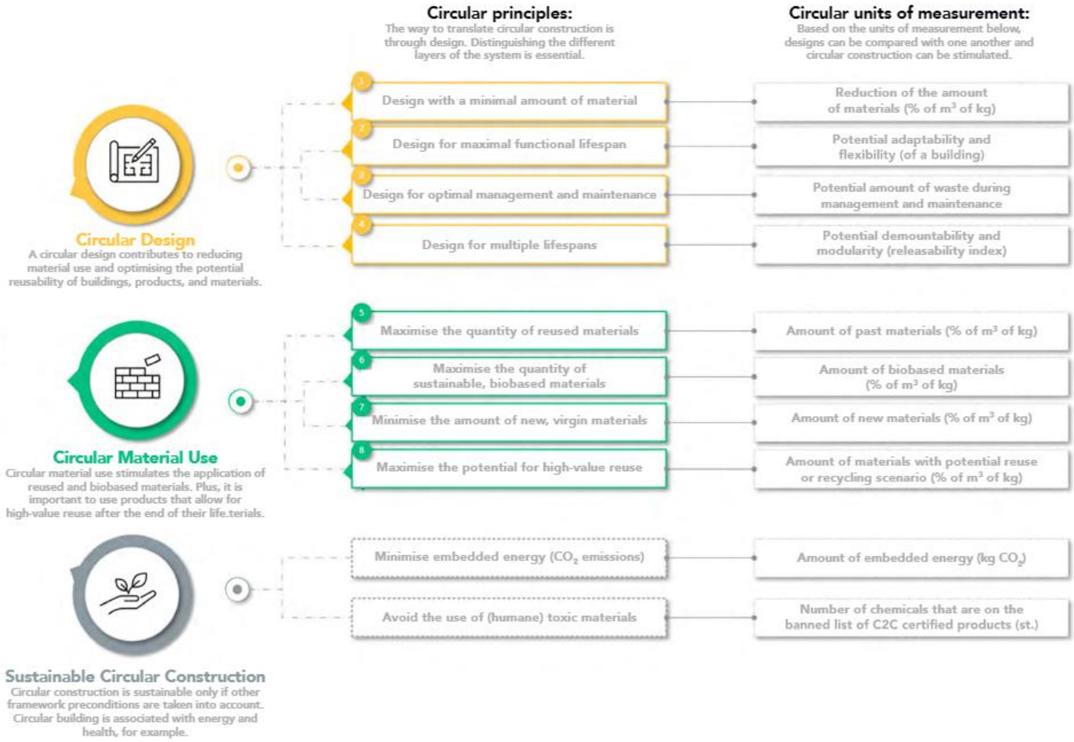

Figure 5: circular construction in 8 principles

Source: Circular design of buildings. The circular tool box. https://www.metabolic.nl/publications/the-circular-design-of-buildings/

3.2 From policies to regulation

As previously explained, the European framework concerning the circular economy is of strategic nature and it is mainly represented by the Circular Economy Action Plan. Dealing with the construction sector, the "Level(s)[7] – A common EU framework of core sustainability indicators for office and residential buildings" has been developed and published in 2017. It has been designed by the EU with the purpose of including circularity in the life cycle perspective and create a common language helping professionals to improve building performance and policy makers to align their legislation to the environmental objectives. It works in support of the harmonization of monitoring strategies and indicators across the Member States.

Level(s) differs from the certification schemes like LEED, BREEAM or C2C since it does not set benchmarks (that should be established at national level, due to the not-homogeneity of the building stock and climate condition in the whole EU) but it is considered more like a set of tools to reflect the different aspects of sustainability. In fact, it is released as **user manuals and reporting templates[8]**, explaining the sustainability concept, how to implement it and how to measure the results. Level(s) is

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[7] https://environment.ec.europa.eu/topics/circular-economy/levels_en

[8] Free download available here

focusing on **six overarching macro-objectives**; for each of them key indicators are identified as it is show in the table below.

Table 2 Level(s) macro-objectives and key indicators

Macro-objective	Indicator	How to measure
1.Green house gas emissions along a building's life cycle	1.1 Use stage energy performance 1.2 Life cycle Global Warming Potential	kWh/m^2/yr kgCO2equivalents/m^2/yr
2. Resource efficiency and circular material	2.1 Bill of quantities	Unit quantities, mass and years
	2.2 Construction and demolition waste and materials	Kg of waste and materials per m2
	2.3 Design for adaptability and renovation	Adaptability score
	2.4 Design for deconstruction, reuse, recycling	Deconstruction score
3. Efficient use of water	3.1 Use stage water consumption	m^3/yr of water per occupant
From 1-3 FULL LCA	10 impact categories	
4. Healthy and comfortable spaces	4.1 Indoor air quality	Parameters for ventilation, CO_2 and humidity
	4.2 Time outside of thermal comfort range	% time out of range during the heating and cooling seasons
	4.3 Lighting and visual comfort	Level 1 checklist
	4.4 Acoustic and protection against noise	Level 1 checklist
5. Adaptation and resilience to climate change	5.1 Protection of occupier health and thermal comfort	Projected % time out of range in the years 2030 and 2050 (see also indicator 4.2)
	5.2 Increased risk of extreme weather events	Level 1 checklist
	5.3 Increased risk of floods events	Level 1 checklist
6. Optimised life cycle cost and value	6.1 Life cycle costs 6.2 Value creation and risk exposure	€/m^2/yr Level 1 checklist

Three are the "levels" identified to map the sequences in a building project: Level 1 is qualitative and involve the conceptual design of the building project with the project definition and the concept design. No metrics are foreseen in this stage. Level 2 is related to the detailed design and construction with the outline of the spatial planning, the detailed design and the technical design (construction project). In this stage there are references to the international standards to use and the methodology that can be applied, quantifying the performance of building design. Finally, Level 3 is related to as-built situation and in-use regime and, therefore, to the monitoring and feedback process of the real building. Each macro-objective is explained in the user manuals together with the indicators, identifying all the aspects to be taken into account according to the level of the project and differentiating the contents in the case of new buildings or deep renovation of existing ones.

As mentioned above, the Level(s) framework is paving the direction for the harmonization of the way sustainability is considered and can be assessed at building level but it is not mandatory to be transposed in the Member States' legislation. However, many states have their own regulation when it comes to the minimum building performance to guarantee. It is particularly interesting the case of the public buildings and Green Public Procurement. As an example, Italy enacted the National Green

Public Procurement Action Plan (2018) in which it is stated that all public procurement must comply with **minimum environmental criteria** (Criteri Ambientali Minimi (CAM) in Italian language). The CAM are requirements defined for the various phase of the purchasing process of the public administrations with the purpose of identifying best design solution, products and services from an environmental point of view. Their systematic and homogeneous application makes it possible to prefer environmentally preferable products and produces a leverage effect on the market, inducing less virtuous economic operators to adapt to the new requests of the public administration. In Italy, the effectiveness of the CAM has been ensured by the transposition of the Action Plan in laws (Law 221/2015 and Legislative Decree 50/2016 and subsequent modifications) which made the CAM application mandatory. The objective is not only to reduce the environmental impacts but to promote a more sustainable and circular production and consumption models. To date, CAM have been adopted in 18 categories of supplies and assignments, among which the construction sector is included.

In the document, the "Level(s)" framework is cited, especially because the recommended use of LCA methodologies and for the consideration of indicators related to the health, comfort and potential risks for the maintenance of adequate levels of performance. The application of the CAM is considering and supports the existing regulations already in place like the directive related to the energy performance of buildings (2010/31/UE), the EU regulation about the construction products (305/2011) and the waste management directive (2008/98/CE). Concerning the integration of circular economy principles, a paragraph is dedicated to disassembly and end-of-life: it is stated that the project relating to new buildings, including demolition works and building reconstruction or renovation, requires at least 70% in weight of the building components subject to disassembly or deconstruction or other recovery operations. The threshold has to be demonstrated through a disassembly and selective demolition plan drafted by the applicant to the tender. Another requirement is related to the use of construction materials (e.g. iron, bricks, wood, concrete, insulation) produced with at least a pre-defined percentage of recycled materials. In addition to the minimum requirements, in the law there are some additional criteria that, if guaranteed by the applicant to the tender, allow to collect extra scores for the evaluation process. As an example, a premium score is attributed to the economic operator who decides to undertake a LCA and LCC study to assess the environmental and economic sustainability of the project as well as the use of BIM technology for the different phases of the construction.

4. Case study

4.1 Circular Building Toolkit

One application of the Level(s) framework is the circular building toolkit[9] that has been developed by the EMF in collaboration with ARUP. It is an attempt to overcome the predominant focus on energy savings and efficiency in buildings towards a more holistic perspective, breaking down strategies and detailed actions that designers and planners can embed in order to integrate circular economy

[9] https://ce-toolkit.dhub.arup.com/framework

principles from the beginning of the projects. The framework is based on four key principles: build nothing, build for long term value, build efficiently and build with the rights materials. Each principle breaks down into strategies and detailed actions for designers and planners to follow as shown in Table 3.

Table 3 Strategies and actions of the circular building toolkit developed by EMF and Arup

Objectives	**Strategies**	**Actions**
BUILD NOTHING	1. Refuse unnecessary new construction	1.1 Reuse, renovate or repurpose an existing asset
BUILD FOR LONG-TERM REUSE	2. Increase building utilisation	2.1 Increase the multi-use potential of building spaces 2.2 Create the general physical conditions to enable multi-use implementation 2.3 Design for an increased utilization of regularly "empty" spaces 2.4 Design local building performance units so that they can work at various space configurations and requirements 2.5 Make us of versatile/flexible/movable internal walls for the space layout to support multi-use.
	3. Design for longevity	3.1 Design for future climate adaptability/ resilience 3.2 Prioritize standardized, modular elements over bespoke/tailor-made solutions, and avoid complex building geometries 3.3 Investigate Product-as-Service schemes for components expected to have a short or medium service life in the project 3.4 Maximize the durability of the building structure through careful selection, protection and maintenance of components 3.5 Ensure the individual service life of envelope systems, components, products and materials align with the minimum service life of the building. 3.6 Make use of Whole Life-Cycle Cost assessment (WLCC) as design assessment tool 3.7 Issue a Building Materials Passport document for the project
	4. Design for Adaptability	4.1 Increase convertibility: choose architectural massing, a structural grid and a foundation layout compatible with all likely future uses 4.2 Increase convertibility: Allow for changes in building use by designing the building envelope to allow for more than one use, or to allow modifications in window size and spacing. 4.3 Increase convertibility: Make passive provision accounting for possible changes to MEP systems, provide a plant replacement strategy that avoids waste. 4.4 Develop and issue an Adaptability Manual document
	5. Design for Disassembly	5.1 Develop reversible connections between the building super-structure elements

		5.2 Allow access to reversible connections between the structure and building services 5.3 Develop and issue a Disassembly Manual Document for the building
BUILD EFFICIENTLY	6. Refuse unnecessary components	6.1 Refuse redundancy in spaces and overestimated headcounts 6.2 Eliminate/reduce the need for on-site parking space 6.3 Prioritise passive and simple servicing strategies over overly complex ones 6.4 Refuse finishes where possible
	7. Increase material efficiency	7.1 Avoid material intensive deep underground and high rise construction 7.2 Reduce the material use intensity in the building structure via material-efficient structural forms and techniques, such as hybrid and/or composite solutions. 7.3 Reduce dimensions of the building structure components through selection of high strength materials 7.4 Use advanced engineering practices to improve material efficiency of structural and envelope components. 7.5 Reduce material waste at production and construction through off-site prefabrication of the building structure and envelope components.
	8. Reduce the use of virgin and non-renewable materials	8.1 Maximize the use of reclaimed components for all building layers 8.2 Use concrete with high secondary content 8.3 Use engineered timber (or other biobased materials) in building structures 8.4 Use bio-based rapidly renewable materials for the interior design concept 8.5 Reduce the use of critical raw materials
BUILD WITH THE RIGHT MATERIALS	9. Reduce the use of carbon intensive materials	9.1 Track the embodied carbon footprint during design and set an ambitious overall embodied carbon target for the project 9.2 Track the embodied carbon footprint of building structure and set a target which is below the regionally recommended thresholds 9.3 Track the embodied carbon footprint of building envelope and set a target which is below the regionally recommended thresholds 9.4 Track the embodied carbon footprint of building systems and set a target which is below the regionally recommended thresholds 9.5 Track the embodied carbon footprint of building fit out components and set a target which is below the regionally recommended thresholds 9.6 Design for digital information management and provide sufficient information for LCA

10 Design out hazardous/pollutant materials	10.1 Track all environmental impacts during design through detailed LCA, not just carbon, and set an ambitious target for the overall project (all layers, including realistic functional and service lives of components) 10.2 Ensure that building materials and products are not on the 'Living Building Challenge (LBC) Red List' 10.3 Use on-site electric equipment to reduce the use of fossil fuel driven machines on site, to in turn reduce the impact of nitrogen, smog and particulate matter emissions in the area 10.4 Avoid the use of hazardous/pollutant materials in the services inside the building. 10.5 Avoid the use of hazardous/pollutant materials in the space 10.6 Manage hazards of legacy materials in existing buildings

Source: https://ce-toolkit.dhub.arup.com/framework

The toolkit includes detailed explanation of all the actions reported above, with indication of key stakeholders, key design phase and available tools. Several examples are also provided, among which the circular building designed and created by ARUP, Frener & Reifer, BAM Construction and The Built Environment Trust, is mentioned here. It consists in a building prototype that aims at exploring how the industry can work towards zero waste, being designed with all elements to be disassembled and reused.

5. Conclusions

The present report outlines the European context when it comes to the circular economy. The framework is mostly of strategic nature but efforts are made by the European Commission to create a common understanding of the phenomenon and consequently to develop guidelines and monitoring approaches upon which all the Member States will base their laws and regulations. The circular economy is seen as an opportunity to tackle the climate change effects and to achieve the carbon neutrality by 2050. In this context, the construction sector is one of the most considered by policy makers and academia since it is responsible for large quantities of emissions and has a significant impact on the waste generation due to the construction and demolition waste. In the manuscripts, the application of the circular economy principle to the building sector is presented through the presentation of the main theories, assessment methods and approaches. Lastly, the circular building toolkit is described. The toolkit is an attempt to overcome the sectorial approach related to the achievement of energy efficiency goals towards the development of a more holistic overview of the opportunities and the impact that the application of the circular economy principles to the construction sector can bring.

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Circular Economy in the Agri-Food Industry in Japan: A Preliminary Literature Analysis on Research Trends

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Abstract

The study focuses on the literature on circular economy in the agri-food industry in hopes to understand the research trends, thus grasping possible avenues for future research. A specific interest lies in the availability of research on Asia and specifically on Japan's efforts to nurture circular economy in the agri-food industry. The Sustainability journal was selected for this investigation as it is one of the leading journals on circular economy. Through the analysis, the study found that the research mainly focused on consumers and their attitudes toward food waste rather than farmers in the upstream food production and their struggles with food loss. Little case studies existed and among those, few took place in Asia with most of the case studies taking place in Europe. The conclusion of this preliminary analysis demonstrated a need for studies taking place in the upstream food production in Asia allowing for this gap to be a potential research avenue. The preliminary study briefly introduces some concrete examples of circular economy in the agriculture industry in Japan for possible future case studies.

Keywords: circular economy, agri-food industry, literature analysis, food waste, food loss

1. Introduction

The aim of this preliminary literature analysis is to understand the current stream of research on the topic of circular economy in the agri-food industry. Since the food supply chain includes the upstream production to the downstream consumption, the study collected articles in both the agriculture and food industry ("agri-food industry" from here on) as some articles may discuss both the upstream and downstream in the research. Through the analysis, the study hopes to grasp possible avenues for future research in the agri-food industry on circular economy with a particular interest in the availability of case studies that take place in Asia and specifically in Japan. For this preliminary study, the *Sustainability* journal was selected as it has been one of the leading journals publishing articles on circular economy. According to a bibliometric analysis conducted by Luis and Celma (2020), between 2016-2019 in which circular economy research seems to have exploded, *Sustainability* published 259 papers ranking second most published on the topic after *Journal of Cleaner Production*. With a plethora of research, the articles extracted provide insights on the research trends over the years leading up to, most recently, 2022. The analysis found abundant circular economy literature and a handful on the agri-food industry. Most studies focused on consumers' attitudes toward household food waste and many of those studies took place in Europe. Few studies existed that focused on the upstream production where farmers may struggle with food loss issues. The preliminary analysis concluded that there seems to be a lack of research on efforts to nurture circular economy in the upstream production, and it identified that the conversation on circular economy will benefit from studies taking place in regions other than Europe. To spearhead such conversations, the preliminary study briefly offers some cases of the agriculture industry in Japan nurturing circular economy.

2. Methods

The preliminary literature review focuses on the *Sustainability* academic journal. In a bibliometric analysis by Luis and Celma (2020) this journal was found to have published 259 papers on the circular economy topic between the years 2016-2019 according to *Web of Science* ranking second to "*Journal of Cleaner Production*" in a list of ten journals. The popularity of the topic in this journal is evident through a search into the closed special issues of the journal resulting in 7 issues with "circular economy" in the title and a total of 60 articles across those special issues. The search did not include special issues which had "circular" without "economy" in order to identify the special issues with circular economy as their definite main topic of interest. The table below summarizes the 7 special issues in terms of editors, years published, title of the special issue, and the number of articles published in each issue.

Table 4 Special Issues in *Sustainability* journal with "circular economy" in the title

Editor(s)	Years of Publications	Special Issue Title	Published Articles
Prida, V. and Sjödin, D. R.	2018	Leveraging Digitalization for Advanced Service Business Models: Challenges and Opportunities for Circular Economy	7
Mugge, R.	2018	Product Design and Consumer Behavior in A Circular Economy	10
Kuo, T., Tan, R. R., Tseng, M., and Tan, K.	2019-2020	Circular Economy in Industry 4.0	12
Mercader-Moyano, P. and Esquivias, P. M.	2020	Decarbonization and Circular Economy in the Sustainable Development and Renovation of Buildings and Neighborhoods	14
Ritzén, S., Laurenti, R., Gusmerotti, N., and Corsini, F.	2020-2021	The Environmental Effects from Consumer Behaviour in the Contexts of the Circular Economy and the Sharing Economy	5
Jaca, C., Reyes, T., and Ormazabal., M.	2020-2021	Circular Economy in Small and Medium Enterprises	7
Tam, E. K. L., Ruparathna, R., and Seth, R.	2021-2022	End of Life Products and Processes in the Emerging Circular Economy	5

Although the years published shows the earliest to be 2018, a general search for literature in the *Sustainability* journal with "circular economy" in the article title without a specification of the years published produced articles from as early as 2016. Hence, the study will focus on articles published between 2016-2022 with the topic of circular economy as the focus of the research. Similar to the search of special issues, the exact wording "circular economy" appearing in the title acted as the first criterion for identifying relevant papers. In the first search through the journal, 37 papers with "circular economy" in the title were extracted for this preliminary study.

2.1 Cataloging

In the next step, each paper was cataloged using the following categories:

- Industry: Such as fashion, food, logistics, appliance, commerce, textile, etc.
- Region of study: Such as Europe, or a specific country such as Romania or Portugal.
- Methodology of study: quantitative (further categorized whether or not the study utilized a survey), qualitative (further divided into a case study or literature review), or mixed methods.
- Research question or the "aim of the paper": For the research question, either a direct question format with a question mark or stating a "how" or "whether" statement. For the "aim of the paper", some papers may not ask a direct question and instead state their objective of the analysis, literature review, or survey. Perhaps they are trying to develop a framework or understand a research trend.
- The hypotheses (if applicable): Depending on the research methods, some papers may not include a hypothesis and some may include more than one.
- Findings and results: Included important notes from the discussion and/or conclusion. For research questions, the direct answers to these questions were extracted. For hypotheses, the results for each hypothesis were extracted including any related percentage data from the surveys conducted.

Next, the preliminary study summarized the findings of each category in detail.

3. Findings

3.1 Industry

Some industries studied were fashion, agri-food, logistics, appliance, commerce, etc. Some studies analyzed multiple industries. For example, one case study focused on the general city level of circular economy activities in Portugal and not a specific industry (de Ferreira and Fuso-Nerini, 2019). Other studies had no specific industry, and many of these were literature reviews (Lewandowski, 2016; Moreno et al., 2016; Gregorio et al., 2018; Lahti et al., 2018), or they aimed to understand the general viewpoints or behaviors of consumers practicing a circular lifestyle in the household (Lakatos et al., 2016). In terms of the agri-food industry, 12 articles focused on the agri-food industry, yet only one article addressed the upstream of the supply chain and its role in the circular economy (Fassio et al., 2022).

3.2 Region of the studies

Most case studies took place in Europe, such as Italy, Romania, Poland, and the Netherlands. Gregorio et al. (2018), who conducted a systemic literature review on bio-economy, green economy, and circular economy literature spanning 1960 to 2017, also found Europe to be the leading region for circular economy literature between the years 2013 to 2017.

3.3 Methodology of the studies

For this preliminary study, focusing on articles with "circular economy" in the title, out of the 37 articles extracted, 12 articles took a quantitative method, and the remaining took a qualitative or had mixed methods of a qualitative case study with a statistical analysis. For example, Bianchini et al. (2022), used mixed methods to assess the supply chain of the textile industry in Italy, propose a framework with social indicators, and finally, to demonstrate how to apply the framework in a way that would help stakeholders make decisions. Out of the qualitative studies, 11 were case studies focusing on a specific industry in a specific region or country, further, 3 of the case studies focused on the agri-food industry.

3.4 Research question or the "aim of the paper" of the studies

For the research question, some papers specifically asked a research question in a direct question format such as "…why are firms unable to transform themselves to compete with business models that are based on the circular economy, and could such a transformation lead to differences in behavior and profitability?" (Lahti et al., 2018). Other papers might imply a question by stating they are asking "how" such as "...we analyse *whether* and *how* SMEs that have successfully introduced circularity into their business models have faced the barriers identified in the literature review, and how they have been able to overcome them," (Rizos et al., 2016, [*emphasis added*]). "Aim of the paper" could be to develop a framework for circular economy design strategies for European businesses (Moreno et al., 2016), to investigate the transition into a circular lifestyle within the household (Mylan et al., 2016), or to identify consumers' attitudes toward remanufactured products (Milios and Matsumoto, 2019).

3.5 The hypotheses of the studies (if applicable)

Some of the quantitative articles included hypotheses, but a few did not. One study included seven hypotheses relating to each of the seven survey questions aimed at consumers in Romania (Lakatos et al., 2016), while others included one to three hypotheses in their studies. Rizos et al. (2016), however, did not disclose any hypotheses yet conducted a statistical analysis on small and medium-sized enterprises of multiple industries in Europe dealing with green innovation.

3.6 Findings and results of the studies

For this category, direct answers to research questions or the results for hypotheses were extracted including any related data such as the percentage of Romanian consumers who agree with a statement about recycling (Lakatos et al., 2016).

3.7 Summary

In sum, it seems that the trend of the circular economy literature in the *Sustainability* journal shows that studies on circular economy often take place in Europe with only one case study based in China (Liu et al., 2018) and one based in Ecuador (Diéguez-Santana et al., 2022). Agri-food industry articles tend to focus on the end consumers rather than the upstream producers. Case studies in the agri-food industry were surprisingly few with only 3 articles out of the 37 articles extracted.

4. Review of circular economy literature

Finally, a shared understanding of the key concept, "circular economy" was identified, and then papers that discuss circular economy in the context of the agri-food industry were extracted. A particular point of interest here is on the extent of research on the agri-food industry relating to the circular economy.

4.1 General definition of "circular economy"

The general consensus on the definition of "circular economy" in the current literature within and outside the journal of *Sustainability* seems to be that the circular economy is a sustainable alternative of linear economy (Murray et al., 2017; Camacho-Otero et al., 2018; Rovanto and Finne, 2022). Linear economy begins by harvesting natural resources, and at the end of the process, produces waste often in the form of pollution which harms the environment (Murray et al., 2017). Circular economy is described as a "closed loop", in contrast, and is seen as environmentally friendly, producing little waste (Borrello et al., 2017; Murray et al., 2017; Rovanto and Finne, 2022). Some literature focusing on circular economy in terms of the food industry have described it as a network involving a variety of players (Borrello et al., 2017).

Some scholars have pointed out, however, that the circular economy literature lacks in terms of addressing the social dimension, focusing mainly on economic sustainability (Murray et al., 2017; Rovanto and Finne, 2022). Circular economy also constricts the role of stakeholders into consumers or users (Murray et al., 2017; Camacho-Otero et al., 2018) and even "ignores" other actors when defining or analyzing circular economy (Camacho-Otero et al., 2018). More recent literature claims that although the social dimension is still lacking, circular economy is gaining traction in sustainability research (Rovanto and Finne, 2022).

4.2 Circular economy and the food industry

When discussing the topic of circular economy in the food industry, the terms "food waste" and "food loss" become necessary to define. According to the *Food and Agriculture Organization of the United Nations*, "food waste" occurs at the decisions and actions of the downstream end consumers, retailers, or food service providers (FAO – food waste, n.d.). In contrast "food loss" happens at the decisions and actions of the upstream food suppliers (FAO – food loss, n.d.).

The studies in the *Sustainability* journal mainly focused on food waste, specifically, end consumers and the food waste produced in their households (Borrello et al., 2017; Camacho-Otero et al., 2018) especially emphasizing a need for a change in consumer attitudes which are thought to be connected to political or social values (Borrello et al., 2017; Camacho-Otero et al., 2018; Hamam et al., 2021; Dudziak et al., 2022). One study elaborates how consumers may develop distrust toward food produced using innovative technologies which would discourage them from accepting certain food products, yet, the study states such distrust can be prevented through innovative policies (Hamam et al., 2021).

Similarly, Fassio and Minotti (2019) have emphasized the need for a circular way for food waste to be managed as food is an integral part of our well-being, and in their study, they integrate food policy into the circular economy. The food chain is a network that connects various actors intricately (Borrello et al., 2017) and this complexity requires a systematic approach. They encourage the proposal of a new policy to insinuate an inclusive community and enable consumers to collaborate to gain better well-being (Fassio and Minotti, 2019).

Other studies have also focused on the social dimension of circular economy in terms of food waste at the consumer end and conducted surveys and analyzed the attitudes of consumers toward food waste and then proposed the need for actions such as educational efforts by non-governmental organizations or policy changes at the government level (Camilleri, 2021; Diéguez-Santana et al., 2022).

A case study of eastern Poland, for example, conducted a survey on 384 people to determine their attitudes toward food waste in their households and found that women tended to be more mindful of food waste and management compared to men (Dudziak et al., 2022). The reasons for food waste were mainly found to be consumers over consumption due to advertisements affecting their attitudes toward expiration dates, or to the visibility of the freshness of the product (Dudziak et al., 2022). The study concluded that identifying concrete reasons for food waste at the level of the end consumer would lead to the development of better strategies for food waste prevention contributing to a circular economy (Dudziak et al., 2022).

Recently, with the support of the local government, some scholars conducted a research project on the agri-food supply chains of Piedmont, Italy, where various stakeholders were involved in the transitions to a circular business model (Fassio et al., 2022). The study broke down the supply chain to identify what issues occurred at what stage of the supply chain (i.e., at the farming of the grapes or at the production of the wine) and circular business model solutions (i.e., using grape pomace to make fabric) were described or proposed by those involved in the project with a focus on the involvement of multiple stakeholders (Fassio et al., 2022).

However, literature in the *Sustainability* journal on circular economy in the agri-food industry is still rather sparse despite a seemingly growing interest among businesses in the agri-food industry to transition to circular practices (Hamam et al., 2021). As summarized above, while the circular economy literature has begun to focus more on the social aspect, in the agri-food industry, mainly end consumers are studied. Moreover, it is surprising to find that little case studies exist that focus on the agri-food industry and which study how food loss is managed on the food supplier’s end. The fact that Europe is currently one of the leading countries in circular economy research only confirms the need for research in other countries as a European framework may not always apply to an Asian or African agri-food industry case, for example. The *Sustainability* articles taking place in Romania or Portugal have confirmed that certain values that consumers hold towards circular economy may be influenced by the specific societies in which they live (Lakatos et al., 2016; de Ferreira and Fuso-Nerini, 2019). In other words, with food production and consumption being essential to our well-being (Fassio and Minotti, 2019), circular economy practices could look rather different across regions due to political and societal influences.

5. Conclusion

As a conclusion to this preliminary study, a potential research gap has been identified. In the *Sustainability* journal, there seems to be a lack of regional diversity in circular economy research. Few empirical case-based studies focus on the agri-food industry, and fewer yet study the upstream production and its food loss challenges relating to the circular economy. Hence, future research will aim to provide the Asian perspective, taking a case-based empirical approach and focusing on the agri-food industry in Japan, specifically on food production and food loss challenges. This research hopes to gain key insights into how solutions to food loss challenges can nurture the circular economy and contribute to the Sustainable Development Goals.

The following table introduces some possible cases for future research in Japan in the agri-food industry which nurture circular economy. Two of which are longer-established companies, and two of which are more recent direct-to-consumer online platforms of fresh produce.

Table 2 Cases in Japan in the Agri-Food Industry

Organization	Start	Description
Co-op Deli Association	1986	Sells the produce which farmers are not able to through traditional distribution channels such as fruits or vegetables which have scratches or have bad shape but are fine for consumption as there is no issue with flavor or safety.
Oisix ra daichi	2000	Provides a distribution channel for farmers to increase their income and provides organic vegetables to health-conscious consumers in the form of meal kits.
PocketMarche	2015	Online platform where farmers sell their fresh produce directly to consumers. Farmers and consumers can interact through a chat system and also meet face-to-face as farmer's market events or farmer-consumer meet-and-greets. The CEO of PocketMarche aims to connect the urban and rural areas of Japan and increase sales of the farmers by promotion of their values, struggles, and dedication to farming quality.
Tabechoku	2016	Online platform where farmers sell their fresh produce directly to consumers and can interact with consumers through a chat system. The CEO of Tabechoku aims for a "farmer's first" approach to help the farmers of Japan increase their sales and decrease their food loss.

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