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2023 (2nd 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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Research Framework of
This Grant-in-aid for Scientific Research

2023 (2^{nd} Year of Research Period)
Development Process of New Methodologies and System Techniques for Circular Economy (CE) :
Application as Key Evaluation Topics for Comparative Case Studies of Advanced CE Companies

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Abstract
Our Circular Economy (CE) research themes were 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" (Research period: 2022-2025, Principal investigator: Kin'ya Tamaki, for Grant-in-aid for Scientific Research, Basic Research (B), Japan). The first CE research theme is to delineate the research framework and to develop five research topics as new methodologies and system techniques as described below: (1) Multi-generational CE value chain management and business model, (2) Cyclical resource supply collection, and recovery,
(3) CE product planning, digital marketing, and customer engagement, (4) Lifecycle design for smart products and services, and (5) Sharing platform and application software. The second CE research theme is to explore how to proceed international trend surveys concerning CE policies in each area and country, and international standards. Based on the results of these trend surveys, comparative case studies of advanced CE companies are conducted in each industry. The purpose of the research paper from the 2023 CE international joint research project is, first, to present the interim findings from the exploration of the five research topics encompassed within "New Methodologies and System Techniques for CE". Second, it aims to demonstrate how these five research topics can be applied as Key Evaluation Topics in conducting comparative case studies of advanced CE companies.

Keywords: Circular economy (CE), CE methodologies, CE system techniques, CE policy, CE international standard, case studies of advanced CE companies.

1. Introduction

"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 (EU) Commission [2016] had 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 CE research themes were 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" (Research period: 2022-2025, Principal investigator: Kin'ya Tamaki, for Grant-in-aid for Scientific Research, Basic Research (B), Japan).

The first CE research theme is to delineate the research framework and to develop five research topics as new methodologies and system techniques as described below [Tamaki, 2022]:

(1) Multi-generational CE value chain management (CE-VCM) and business model,
(2) Cyclical resource supply collection, and recovery,
(3) CE product planning, digital marketing, and customer engagement,
(4) Lifecycle design for smart products and services, and
(5) Sharing platform and application software.

The second CE research theme is to explore how to proceed international trend surveys concerning CE policies in each area and country (Japan, EU, USA), and international standards. Based on the results of these trend surveys, comparative case studies of advanced CE companies are conducted in each industry such as automobiles, electronics and devices, construction, food and agriculture, and software and platforms.

The purpose of the research paper from the 2023 CE international joint research project is, first, to present the interim findings from the exploration of the five research topics encompassed within "New Methodologies and System Techniques for CE," which are related to the first research theme mentioned above. Second, it aims to demonstrate how these five research topics can be applied as Key Evaluation Topics in conducting comparative case studies of advanced CE companies, which are associated with the second research theme.

2. CE International Trend Surveys and Comparative Case Studies of Advanced CE Companies

Our international CE collaborative research team is engaged in the following two research issues:

(1) International trend surveys on CE policy and international standardization in each area and country (Japan, EU, USA), and
(2) Comparative case studies regarding advanced CE companies in each industry.

2.1 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., Japan, USA, Germany, Italy)
4) Level of industry associations and unions in each same industry, and academic research trends within individual academic fields.

2.2 Research Approach for Comparative Case Studies of Advanced CE Companies in Each Industry

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

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

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

Step2: As indicated in **Table 2.1**, our international CE collaborative team researchers are responsible for determining the respective industrial fields.

Table 2.1 FY 2023 Research role sharing of comparative case studies of advanced CE companies

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

Step 3: Competitive Analysis among Advanced CE Companies in the Same Industry

The competitive analysis among companies in the same industry is proceed as follows:

(1) Select major companies in the industry based on their competitive position in final product assembly such as a leading company first, and challenger companies,

(2) Identify the major supplier companies associated with each final product company.

(3) Analyze the distinctive strengths of each corporate group in terms of CE management strategies

and business activities.

Step4: Application as Key Evaluation Topics for Comparative Case Studies of Advanced CE

The findings from the competitive analysis of each corporate group are used to apply the content of the five aforementioned research topics as key evaluation indicators for the comparative analysis of advanced CE companies. This helps clarify the progress and trends in CE management strategies and business activities within the industry.

Step5: Comparative Research of Advanced CE Corporate Groups Across Countries

In terms of the differences in the features associated with the five research topics, this study conducts comparative research on the characteristics of each company's CE management strategy and business activities within the same industry and across different countries (Japan, the USA, Germany, and Italy).

3. Research and Development of New CE Methodologies and System Techniques

As mentioned above, the second purpose is to delineate a research framework to develop five new CE methodologies and system techniques in our research team. The research framework for research and development of five new methodologies and system techniques are described below (**Figure 3.1**):
(1) Multi-generational CE value chain management (CE-VCM) and business models,
(2) Cyclical resource supply, collection, and recovery,
(3) CE product planning, digital marketing, and customer engagement,
(4) Lifecycle design for smart products and services, and
(5) Sharing platform and application software.

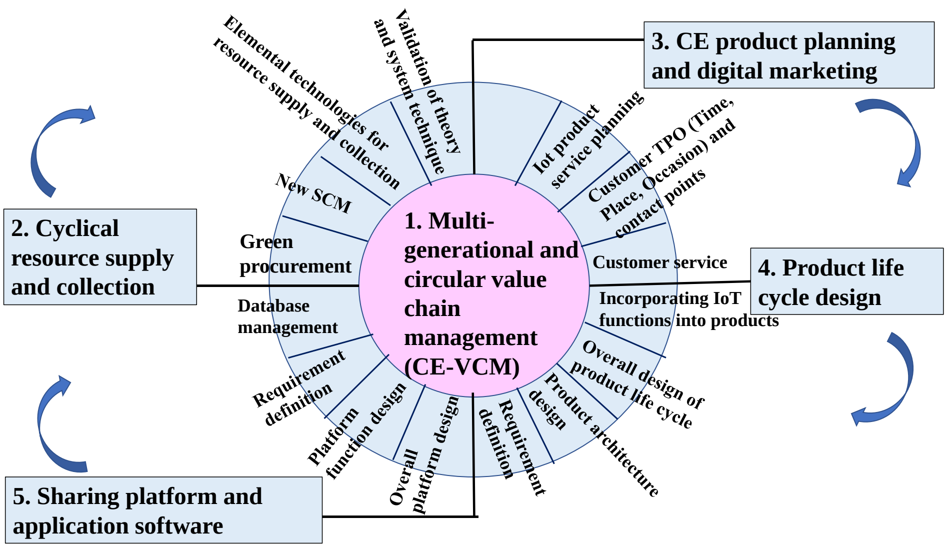

Figure 3.1 CE New Methodologies and System Techniques

4. Multi-generational and CE Value Chain Management and CE Business Models

With the “Multi-generational CE value chain management (CE-VCM)” as the central axis in **Figure 3.1**, the surrounding four relevant research topics are to develop "CE methodologies" and "CE system techniques" by full use of advanced technologies. The first research issue is to develop the CE-VCM compatible with the characteristics of CE oriented business models.

Accenture consultants Lancy and Rutqvist set out “five new business models for circular growth” [Lancy and Rutqvist, 2015], similar to the various business models included in the “technological cycle” in the mentioned above **Figure 4.1** the “butterfly model” by Ellen Mac Arthur Foundation.

- **Product as a service**: Provide access to products and equipment, including contracts for performance, and include incentives so that products last longer and can be maintained, repaired and upgraded.
- **Sharing platform**: Increase product utilization by enabling users to use and/or exchange products and services.
- **Product life extension**: Prolong the useful life of products and components thorough resale, repair, remaking, and upgrading.
- **Recovery and recycling**: Recover useful resources or energy from end-of-life products or production waste, thus turning waste disposal costs into revenue.
- **Circular supply chain**: Provide renewable energy, and bio-based or fully recyclable materials so the same resources can be used again and again.

Brohen and her colleagues [2016] described three “fundamental strategies towards the cycling of resources: slowing recourses loops, closing resources loops, and narrow resource loops. Building on their work, Weetman [2021] had chosen four calusar business models as follows:

- **Slow the flow**: Use the products and materials over a long period of time to get more life out of the same materials.
- **Intensify the loop**: Use the products and materials more intensively, more productively – in other words, get more usefulness out of the same materials.
- **Close the loop and regenerate**: Recover the products and materials, sort and process them so they can be used again ideally with minimum intervention (energy, materials, etc.). In addition, regenerate lost materials, soil, land, water, and living systems to provide valuable services and future resources.
- **Narrow the loop**: Reduce materials, energy, and other resources used at a systems level. Clearly, this model can underpin all others.

The CE butterfly diagram mentioned above consists of a biological cycle and a technological cycle. In research topic “1. CE-VCM” based on product services mainly focuses on the latter “technical cycle”. This technical cycle consists of stakeholders and business activities, such as recyclable resource supply, parts manufacturers, product manufacturers, customer service companies, 3Rs and resource recovery. The following key concepts should be considered when building the new CE-VCM model that reflects each industry characteristic:

- After collecting used product services, build a CE-VCM connected to the next-generation product services while 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 the engineering chain related to the development and design of CE product services.
- The CE-VCM realizes value co-creation that can continuously provide services aligned 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.
- 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 ESG (Earth, Society, Governance).

5. Cyclical Resource Supply, Collection, and Recovery

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

- Investigate trends in regulations and laws related to green procurement such as ISO 20400 and sustainable procurement and OECD Due Diligence Guidelines
- Deviate from the “3Rs (reuse, reduce, recycle) model” and 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 methodologies and system techniques corresponding to product types, service types, and B2B/B2C business models

The aforementioned “J4CE Noteworthy Cases [2021 Edition]” included a case study on recycling plastic food packaging under "Noteworthy Area 6. Cooperation on Production, Distribution and Collection." Plastic recycling required cooperation between manufactures, dis tributers and collection systems. While food tray recycling was already carried out, new initiatives was introduced, promoting recycling through cooperation between similar business categories for packaging of daily necessities and encouraging large retailers to organize collection systems.

The "FPCO company's new recycling method " was launched in 1990 with over-the-counter collection at six supermarkets. It consisted of three processes: collection, recovery of raw materials and recycling as new goods. The main features of this collection method were that it made effective use of trucks returning from delivering the company's products, and it used a horizontal "tray to tray" recycling method for trays. Their method had established as a social infrastructure for more effective use of these used containers as resources as shown in **Figure 5.1**.

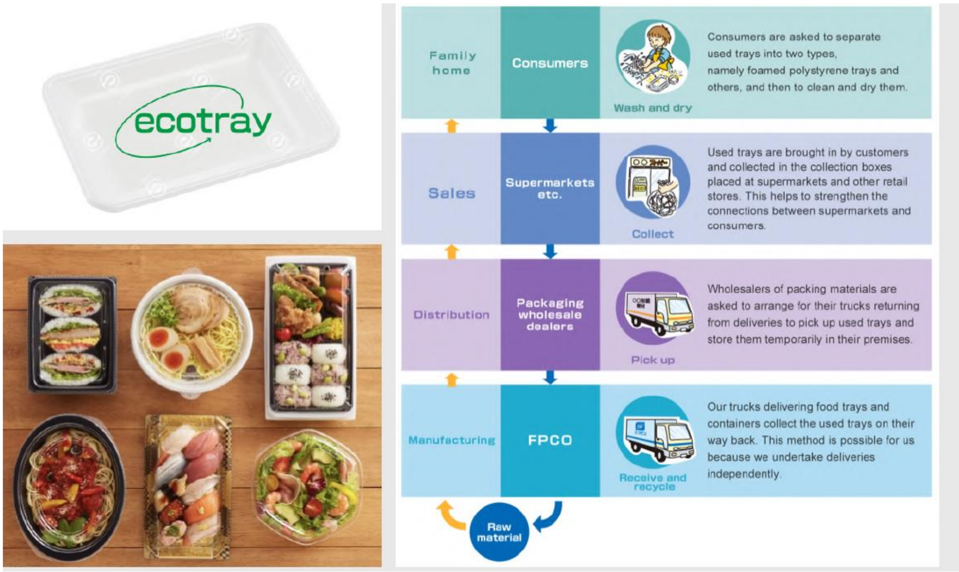

Figure 5.1 Food Tray Recycling with Cooperation on Production, Distribution and Collection [Keidanren, 2021]

6. CE Product and Service Planning, Digital Marketing, and Customer Engagement

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

- As the new methodology of "CE product and service planning", after conducting "persona analysis" to discover future target customers corresponding to CE-VCM, product and service planning can be implemented in the following three areas: 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 product lifecycle management (PLM) software when developing new system techniques for “CE product and service planning”, construct and manage various Bill of Materials (BOM)

databases corresponding to the series of planning processes: 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

7. Lifecycle Design for Smart Products and Services

The role of products and services is to collect each customer's usage experience data from the “smart products with IoT (Internet of Things) function” purchased and used by customers, and to deliver the collected data to the “sharing platform” via the internet. In addition, the platform analyzes the usage experience data, and then sends one-to-one marketing tactical information using AI to provide appropriate services to individual customers. An example of modern IoT smart products are the smartphones used by many customers.

- The methodology of the “lifecycle design for smart products and services” consists of the following design steps:

(1) Choosing an appropriate model from the several mentioned above business models for smart products and services such as businesses completed by selling the products to the customer, rental/lease, sharing services, subscriptions, etc.
(2) Developing lifecycle design for smart products and services according to multi-generational work flows compatible with CE-VCM
(3) Constructing product architecture design for individual products and services, and product lineup strategy for multi-generational products and services such as product family design in relation to (2) above

- For the system techniques of “lifecycle design for smart products and services”, the product architecture is detailed in the following three levels (**Figure 7.1**):

(1) Finished product level: basic overall design for the product architecture of the products and services
(2) IT system level: control systems and software systems (OS, middleware, and application software)
(3) Component/ programming level: product mechanisms composed with overall product configuration/ modular components/ parts and devices, and interfaces between each other

- Complementing the system techniques of the three levels mentioned above, the engineering design method of "functional specifications" include 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 lifecycle design methodology and technique into a practical manner, the aforementioned PLM software was used to create various BOM databases corresponding to the processes involved in "lifecycle design".

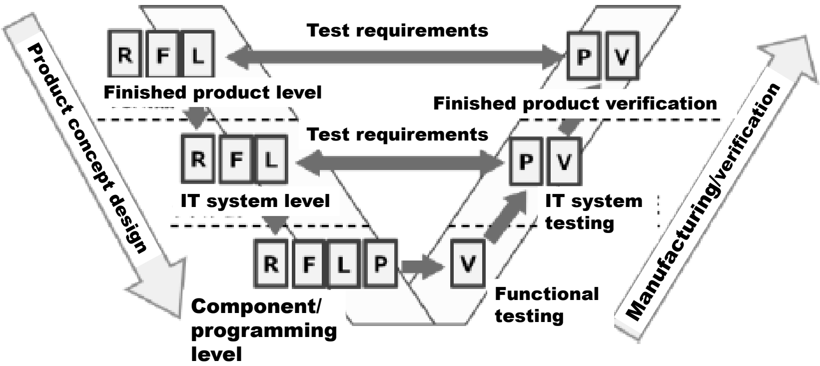

Figure 7.1 System Engineering Process [Young Won, Abe, 2016]

8. Sharing Platform and Application Software

The important role of the "sharing platform” is to quickly carry out mutual information transmissions between the platform and application software, namely, the smart products with IoT function, by using customers. Next, the role of “application software” is to accumulate and analyze each customer's usage experience data by utilizing the individual customers’ database and data processing functions within the platform. The third role is one-to-one marketing that responds to the preferences of each customer (referred to as "individual customer") while integrating with the digital marketing system techniques mentioned above.

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

- Methodology for the overall design of “sharing platform”: Define individual customer service contents to be appropriately provided to the individual customer corresponding to the flow of work steps included in the CE-VCM business process. Stakeholders 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.
- Methodology 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" used with the individual customer. When a customer wishes to use this platform, they must download the application software from the platform into his/her own smart product terminal, and enter their individual attribute information at the same time. As a result, when collecting, accumulating, and analyzing usage experience data, overall usage experience data processing for individual customers within the platform can link with individual customer ID (for example, membership number ID).

- System technique for defining functional specifications: To design the "platform information communication system" that follows the work steps of the data processing of the overall design detailed above.
- Database management (DBM) system techniques for the individual customer: While individual customer uses the platform and application software, the customer usage experience data is collected, accumulated, and analyzed in the platform DBM for the individual customer. In order to design the DBM to provide one-to-one marketing tactics, the following items are created: information processing algorithm, interface requirements definition between internal platform, DBM, and external systems.

9. Conclusion

Chapter 2 presented the research procedures and methods related to the following two types of research issues: (1) International trend surveys on CE policy and international standardization in each area and country (Japan, EU, USA), and (2) Comparative case studies regarding advanced CE companies in each industry. The five research topics mentioned later would be applied as Key Evaluation Topics when conducting comparative case studies of advanced CE companies.

Chapter 3 described the five research topics new methodologies 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 CE value chain management (CE-VCM) and business models,
(2) Cyclical resource supply, collection, and recovery,
(3) CE product planning, digital marketing, and customer engagement,
(4) Lifecycle design for smart products and services, and
(5) Sharing platform and application software.

The following chapters present the interim findings on the research progress for each research topic.

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Automotive Sector

Commitment to Sustainable Business and Circular Economy: Japanese Automotive Industry Case

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Abstract.

The Circular Economy model represents a dramatic transition from the long-employed linear economy (take–make–use–waste) into a regenerative one in which products and materials are kept within the economy through recovery processes including reuse, repair, refurbishment, remanufacturing, and recycling. Numerous social, political, and technical strategies are being considered, and to some extent, implemented to affect this necessary change. All the governments are developing their standards and rules to support and foster CE. As Japan is a pioneer in Circular practices adoption and has formed a relatively well-round legal system. This research aims to study the regulatory landscape at international and national levels at the example of Japan. Along with them, multinational corporations, associations and alliances are striving to step forward CE practices adoption. While the range of organizations participating in these efforts is exceptionally diverse, much of the burden of bringing this vision to a reality will be placed on those who produce goods—i.e., manufacturers. The manufacturing sector is especially vital in facilitating the transition to a CE: not only are they responsible for production operations and resource use therein, but manufacturing firms also make key decisions regarding material and product design, sourcing, procurement, and assembly. Moreover, the purpose of this research is to analyze the policy regarding CE in automotive industry of Japan and the actions of car manufacturers in terms of CE. This report presents key takeaways and outcomes from automobile manufacturing case analysis and steps for addressing standards in terms of CE.

Keywords: Circular Economy, Automotive industry, Regulations, Toyota Motor Corporation, Value Chain, Resource recovery and recycling, Product life cycle.

1.Introduction.

Interest and efforts to transition away from a linear—take, make, use, discard—economic model and toward a more circular economy (CE) have increased significantly in recent years. A CE aims to keep products and materials in the economy—and out of unwanted sinks such as landfills, incinerators, and the environment—for as long as possible through recovery processes including reuse, repurpose, repair, refurbishment, remanufacturing, and recycling. Considerable time, thought, and energy is being directed towards enabling this transition. Numerous social, political, and technical strategies are being considered, and to some extent, implemented to affect this necessary change. The manufacturing sector is especially vital in facilitating the transition to a CE: not only are they responsible for production operations and resource use therein, but manufacturing firms also make key decisions regarding material and product design, sourcing, procurement, and assembly. Together, these have a profound impact on the feasibility and practicality of employing circular practices. However, improving the ability of manufacturers to foster a CE requires consensus-based industry standards to support harmonization, consistency, reliability, and ultimately build trust within the marketplace.

Several international and national standards bodies are developing CE-related standards and each brings a different perspective. The International Organization for Standardization (ISO) is perhaps the leading international organization developing management standards that will be instrumental to supporting a CE. Moreover, governments are developing their standards and rules to support and foster CE. Along with them, multinational corporations, associations and alliances are striving to step forward CE practices adoption.

The aim of this research to analyze the policy regarding CE in automotive industry of Japan and to study the strategies and actions of car manufacturers in terms of CE. Accordingly, next questions motivate this work: **Q1. What regulations and standards have been developed regarding CE? Q2. How leading automotive companies support their sustainable development in terms of CE?**

This report presents key takeaways and outcomes from automobile manufacturing case analysis and steps for addressing standards in terms of CE. Section 2 provides the role of standards in relation to policy. Section 3 then presents key takeaways from the Car Manufacturing Circular Economy Case Analysis regarding current sustainable and circular manufacturing practices and opportunities for new innovations regarding circularity. Section 4 provides a summary for each section.

2. Regulatory landscape

2.1. International standard (ISO, CE Technical Committee, ISO/TC323) level

Governments worldwide are increasingly implementing policies and regulations to promote Circular Economy practices. Currently, technical and strategic standards are being developed and refined in various bodies at all three levels – national, regional and international – in particular to accelerate the transformation of more circular products and services.

2.1.1. International level – ISO Technical Committee 323 to promote Circular Economy

The International Organization of Standardization (ISO) has a suite of management standards that support sustainable manufacturing practices (Table 1). ISO standards are international agreements approved by representatives through consensus, and thus represent internationally-recognized best practices for their fields. The organization is comprised of a global network of 167 national standards bodies which represent ISO members [1]. These members are the foremost standards organizations from individual countries, and there is only one member per country; thus, each member in turn represents ISO within its own country.

Table 1 Existing ISO Standards that Support Manufacturing in a CE [2]

Standard Title and *Responsible ISO/TC*	Description
ISO 9000: Quality Management *ISO/TC 176*	Series of standards that describes the fundamental concepts and principles of quality management systems for manufacturing and service industries (International Organization for Standardization 2015b).
ISO 14000: Environmental Management *ISO/TC 207*	Series of standards that help organizations minimize the environmental impact of their operations. Specifies requirements for the development and implementation of environmental management systems (International Organization for Standardization 2015a; ISO 2019).
ISO 50001: Energy Management *ISO/TC 301*	Specifies requirements for establishing, implementing, maintaining, and improving an energy management system (EnMS) (International Organization for Standardization 2018b).
ISO 20140: Evaluating energy efficiency and other factors of manufacturing systems that influence the environment *ISO/TC 184*	Provides principles and guidelines for the evaluation of energy efficiency and other factors of manufacturing systems that influence the environment (International Organization for Standardization 2019).

At a global level, the International Organization for Standardization (ISO) is the leading international organization developing management standards that will be instrumental to supporting a CE. The new ISO Technical Committee (TC) 323 on Circular Economy will provide principles and a framework for how to define and manage CE globally. Created in 2018, currently this Technical Committee produces some transversal standards related to Circular Economy. The purpose of this Committee is Standardization in the field of Circular Economy to develop frameworks, guidance, supporting tools and requirements for the implementation of activities of all involved organizations, to maximize the contribution to Sustainable Development. It is composed by 75 participating members and 20 observing members [2].

The purpose of this Organization is to propose an answer to environmental and social emergencies with an economic alternative; towards a new mindset that promotes Circular Economy; provide operational standards for users to implement the circular economy in organizations as soon as possible; develop standard to be implemented by SMEs from all geographies; be collaborative within the Technical Committee.

2.1.2. International partnership

Global Alliance for Circular Economy and Resource Efficiency（GACERE)

The **Global Alliance on Circular Economy and Resource Efficiency (GACERE)** is an **alliance of governments** at the global level willing to work together on and advocate for a global just circular economy transition and more sustainable management of natural resources at the political level and in multilateral fora. GACERE was launched in February 2021. Bringing together governments and relevant networks and organizations, GACERE aims to provide the global impetus for initiatives related to the circular economy transition, resource efficiency and sustainable consumption and production, building on efforts being deployed internationally [3].

Purpose and Activities of this Alliance are:

Aiming for a just global transition to a circular economy and efficient use of resources.

Mapping country policies, identifying challenges, and sharing best practices.

Promote investigation and research into issues and policy gaps.

Supporting sectoral, bilateral and regional partnerships (e.g. African Circular Economy Alliance, Latin American and Caribbean Circular Economy Alliance).

Fostering a global dialogue on resource management.

Members of the Alliance: The participating countries and institutions (18 countries and institutions) as of August 2021 are as follows: EU, Japan, Canada, Norway, Chile, Peru, Colombia, South Africa, Kenya, Rwanda, Nigeria, Morocco, South Korea, New Zealand, India, Switzerland, UNEP, UNIDO

2.2.1. National level

So, what are the policy issues facing Japan, and how is the circular economy dealt with in a Japanese policy context? 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 [4]. This Act focuses on the promotion and implementation of the 3Rs, reduce, reuse and recycle, proper waste management and a reduction in environmental impact [6]. 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 [5],[7]. 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 [8], which was officially put into effect on January 1, 2005. On the next picture we can see the timeline of regulations that have been accepted and enacted to facilitate the Circular Economy practice and to sustain the automotive industry as well.

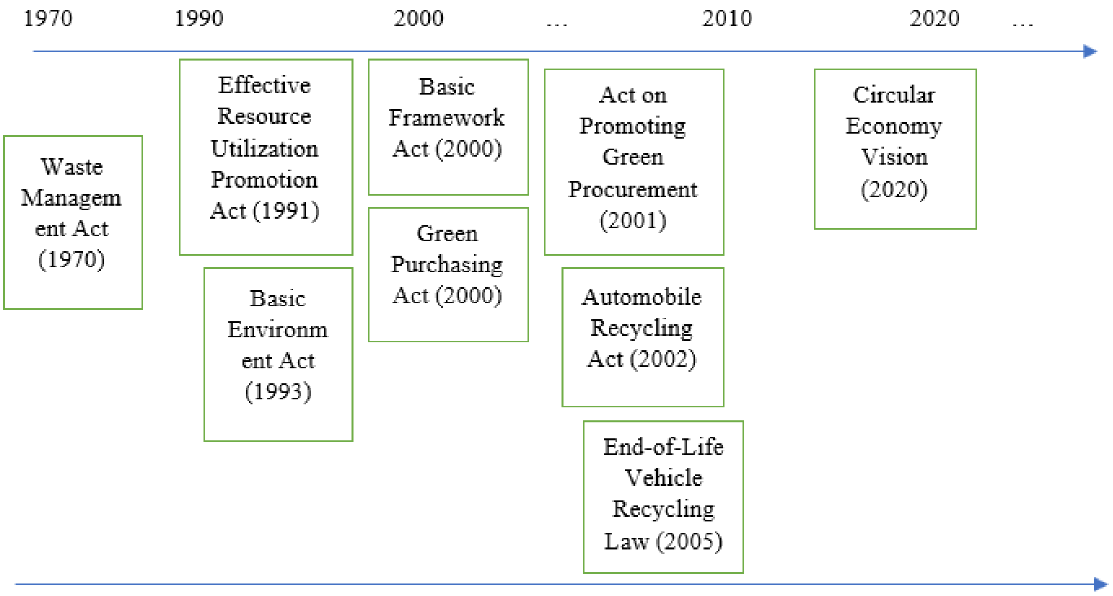


Figure 1. Timeline view of regulations

From the Figure 1 we conclude Japanese government has implemented various regulations to promote the adoption of circular economy principles in the automotive sector. It has started from 1970 by implementation of Waste Management Act

Ministry of Environment

The Japanese Sound Material-Cycle Society plan is led by the Ministry of Environment (MoE), and it aims to resolve key socio-ecological issues in Japan and globally by taking an integrated approach that includes the three pillars of sustainability (environmental, economic, and social). The core of the Fundamental Plan for Establishing a Sound Material-Cycle Society has always aimed to create a resource-productive SMCS that moves away from mass production and consumption-oriented technologies, systems, and institutions. It seeks to strengthen international partnerships to overcome social issues related to CE, and it aims to break Japan's economic stagnation and achieve medium- to long-term economic growth [9].

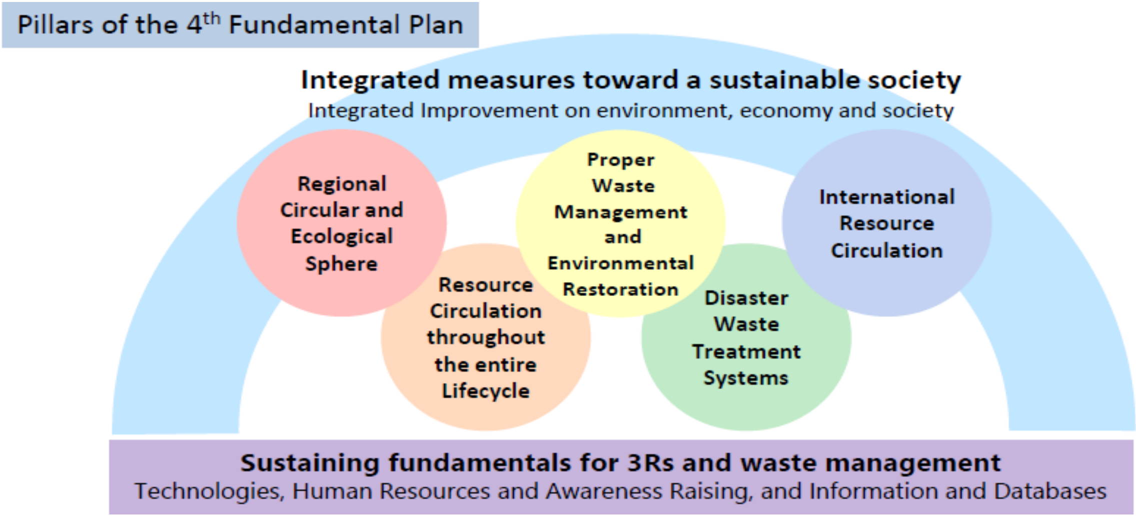


Figure 1. Pillars of the 4th Fundamental Plan [9]

The 4th Fundamental Plan was approved by the Cabinet on June 19, 2018, which indicates measures to be implemented in a strategic manner (Figure 1).

There are Four main indicators for monitoring progress:

Resource productivity – target for 2025 is 490,000 JPY/ton,

Final disposal amount – target for 2025 is 13 million tons,

Cyclical use rate (resource base) – target for 2025 is 18%,

Cyclical use rate (waste base) – target for 2025 is 47%.

The Ministry of Economy, Trade and Industry (METI)

While the MoE updated the Fundamental Plan in 2018, the Ministry of Economy, Trade and Industry (METI) reviewed the existing resource recycling policy, and it published the 'Circular Economy Vision 2020'. The Vision underlines the necessity of Japan's transition to CE and suggests the direction to follow to tackle the increasing urgency of domestic and international environmental issues [10].

Japan Business Federation – Keidanren

KEIDANREN (Japan Business Federation) is a comprehensive economic organization with a membership comprised of 1,461 representative companies of Japan, 109 nationwide industrial associations and the regional economic organizations for all 47 prefectures (as of April 1, 2021). Its mission as a comprehensive economic organization is to draw upon the vitality of corporations, individuals and local communities to support corporate activities which contribute to the sustainable development of the Japanese economy and improvement in the quality of life for the Japanese people [11]. For Japan to achieve its goal of carbon neutrality in 2050 and create a sustainable society, achieving green growth is indispensable. Keidanren advocates “Integrated Environmental Corporate Management,” recognizing environmental issues such as climate change, resource circulation, biodiversity, and environmental risk management as key business challenges. In June 2020 Keidanren commenced “Challenge Zero” initiative targeting carbon neutrality. Meanwhile, Keidanren is promoting proactive initiatives such as “Commitment to a Low Carbon Society” and “Voluntary Action Plan for Establishing a Sound Material-Cycle Society”. Keidanren is also actively pursuing dialogue and collaboration with governments, business communities, and others inside and outside Japan, and has agreed with the Ministry of the Environment to further collaborate toward realizing a decarbonized society (September 2020), compiled a policy proposal entitled “Toward Realizing Carbon Neutrality by 2050 (‘Society 5.0 with Carbon Neutral’) — Determination and Actions of the Business Community” (December 2020), and established the Japan Partnership for Circular Economy (J4CE) (March 2021)

2.2.2. Partnership on a national level.

Japan Partnership for Circular Economy (J4CE)

The “Japan Partnership for Circular Economy (J4CE)” was founded (2 March 2021) for the purpose of strengthening public and private partnerships, with the aim of further fostering understanding of the circular economy among a wide range of stakeholders, including domestic companies, and promoting initiatives in response to the accelerating global trend toward a circular economy.
Founding organisations: MOE, METI, Keidanren (Japan Business Federation)
Participating companies and organisations: (1) Member companies and organizations of Keidanren (2) Companies and organizations that agree with the purpose of J4CE, wish to participate, and have been approved by the founding organizations.
Plan of Activities:
1. Collect and share examples of advanced circular economy initiatives in Japan Provide information of cases/initiatives on this website Publish a brochure of noteworthy cases/initiatives Disseminate information through PR events etc. for the general public
2. Information-sharing and networking on the circular economy Share latest information from domestic and around the world Hold annual meetings, etc.
3. Organize dialogues to promote the circular economy[12].

2.2.3. Industry associations

Along with above mentioned Ministries and Partnership Organization in Japan there are number of industry associations which were established with the aim of support the collaboration and cooperation between companies to facilitate and foster Circular Economy practices. In the table below we provided the list of such associations, which set main activities to achieve their goals in terms of Circular Economy and Sustainable Development.

Table 1. Main Japanese Industry Associations in terms of CE.

Name of Organization	Established Data	Purpose	Activities
Circular Economy Association	2021	to encourage the companies to implement "circular business" and have a vision and business plans for circular economy and sustainable development	- To identify what circular economy is and design "circular business" as a circular economy implementation that contributes to achieving circular economies. - To provide support for organizations and individuals to enhance the implementation of "circular business" and promote collaboration between them. - To cooperate with relevant organizations worldwide to exchange information for rule-making, which accelerates to achieve circular economies [13].
Japan Environment Association (1977)	1977	To provide information on aspects of the environment and guiding the actions of consumers and businesses toward the formation of a sustainable society.	To encourage the usage of recycled plastics and bio-plastics ・To develop criteria that promote Reduce and Reuse ・To be not subject to Eco Mark certification for disposal products of the one-way products such as plastic shopping bags as before from the viewpoint of proper use of resources ・To cover bio-degradable plastics only if it is limited to applications that are used in the environment, difficult to take back, and exhibit biodegradable performance ・To expand the scope of product-service systems that reduce the environmental burden of society as a whole, such as sharing services [14][15].

The Green Purchasing Network (GPN)	1996	To disseminate the concept of, and promote the practice of green purchasing among the central and local governments, businesses, and consumers. To provide guidelines and information necessary for practicing green purchasing.	Support for promoting of green purchasing The GPN provides training sessions and seminars for both newly appointed and experienced personnel of local governments to promote green purchasing in their municipalities. The GPN also helps local governments with developing their own procurement policy, manual, and training materials [16].
The Japan Environmental Management Association for Industry (JEMAI)	1962	to cope with problems arising from conventional industrial pollution issues to global environmental issues	- environmental assessments; - technology developments; - surveys for air and water pollution, noise, vibration, and hazardous chemical substances; - global environmental issues[17].
Sustainable Management Promotion Organization (SuMPO)	2019	To achieve sustainable business management by supporting the iterative improvement activities (plan-do-check-act) of new business models, which lead to resolve social and environmental issues.	For resolving social and environmental issues, such as global environmental problems: 1. Company survey, market research, environmental conscious analysis, etc. 2. Building a new business model, designing a promotion plan, etc. 3. Economic (ripple) effect analysis, environmental impact assessment, etc. 4. Public relations activities[18].
NGP Japan Automobile Recycling Business Cooperative	1985	To provide recycled parts that the times demand throughout an expanding national network	・Promoting the acquisition of ISO joint certification (ISO9001/14001/27001) ・Various training/study sessions ・Disaster support, volunteer activities ・Social contribution activities ・Local activities by each member[19].

From this table we can see the established data of associations, for instance **The Japan Environmental Management Association for Industry (**1962), **Japan Environment Association (1977)**, **NGP Japan Automobile Recycling Business Cooperative (**1985). From this data it is obviously that Japan is a pioneer and one of the first countries which tries to think about not only economic benefit of the business but more attention is paid for environment and social factors from past years till it is continuing now. Probably, there might be many practices in automobile industry regarding Circular Economy that implemented and can be a good case for studying and taking as an example for the other industries. For that in the next section we tried to study the Japanese automobile companies' strategies and their commitment to the Circular Economy in three big car auto manufacturers in Japan (Toyota, Nissan, Honda).

2.3. Company level – Japanese Automobile companies.

Manufacturing companies play a great role in fostering Circular Economy practices. Along with the International standards and National regulations automobile manufacturers establish their own policies and strategies to achieve their goals and to be on the same wave with the external pressures. As automobile industry is one the biggest industry in Japan it plays crucial role in the adoption of Circular Economy practices. In the world of automobile manufacturing, Japanese companies like Toyota, Honda and others have long been known for their efficiency and commitment to innovation and implementation them into practice. In the next table, we will make a small analysis of Japanese companies in terms of their efforts toward implementing Circular Economy principles.

Table 2. Automobile manufacturing companies' strategies in terms of CE.

Company name	Strategies and Policy regarding Circular Economy and Sustainable Development	Key points
Toyota Motor Corporation	Toyota Environmental Challenge 2050 (2015)	**Circular Value Chain Management:** Eco-Vehicle Development Material Innovation and Usage Waste Reduction and Management Remanufacturing and Refurbishing Research and Development **Sustainable Supply Chain Management:** Green Purchasing Policy, the Green Supplier Requirements **End-of-Life Vehicle Recycling:** Toyota Global Car-to-Car Recycle Project Toyota Global 100 Dismantlers Project **3R Battery Initiative**
Nissan	Ambition 2030 - Driving innovation to enrich peoples' lives (2021), Nissan's Circular Economy Concept	**Initiatives to Expand Use of Recycled Materials (Ferrous and Nonferrous Metals)** **Initiatives to Expand Use of Recycled Materials (Resins)** **End-of-Life Vehicle Recycling** **Developing Biomaterials** **Proper Use of Regulated Chemical Substances** **Expansion of Remanufactured Parts** **Joint Venture to Promote Second-Life Use for Batteries**
Honda	2030 Vision - Serve people worldwide with the "joy of expanding their life's potential" (2018), Triple Zero Concept (2011)	**3R Pre-Assessment System** Design Focusing on Reduction Design Focusing on Reuse/Recycling Recycling of End-of-Life Components **Initiative for Automobiles** **Initiative for Motorcycles**

3. Towards to Circular Economy: Toyota Motor Corporation Case

3.1. Circular Value Chain Management

Toyota, the globally acclaimed automobile manufacturer, has continually demonstrated leadership not only in producing high-quality vehicles but also in championing sustainable practices. A critical aspect of Toyota's sustainability agenda is its commitment to the circular economy and recycling.

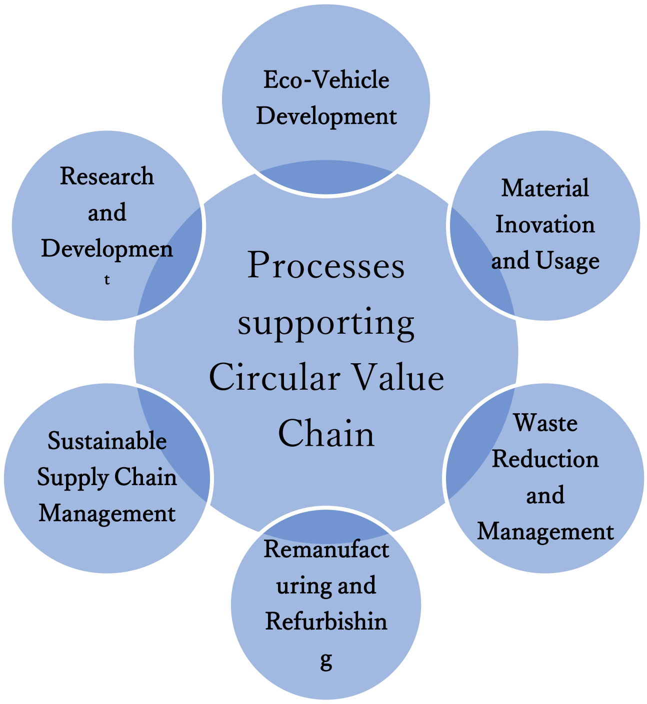


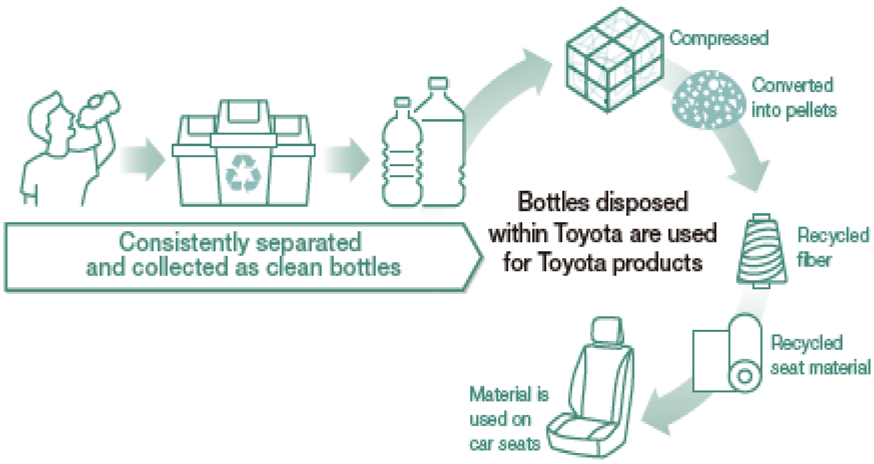
Figure 2. Processes supporting Circular Value Chain

1.Eco-Vehicle Development: Toyota is at the forefront of developing eco-friendly vehicles, such as hybrid, plug-in hybrid, electric, and fuel cell vehicles. These innovations reduce dependency on fossil fuels, decrease emissions, and utilize sustainable materials, aligning with the principles of a circular economy. **What does Toyota do to make their products and materials circular?** Toyota has designed their cars to be more easily dismantled at their end of life. The chassis mountings, wiring harnesses, and interior panels have all been designed to allow for the cars to be dismantled with lower energy costs. This also means that more parts can be removed intact, making it easier to reuse them in new vehicles [20].

(2) Material Innovation and Usage: Toyota pioneers the use of sustainable and recyclable materials in vehicle manufacturing. From bio-based plastics to recycled metals, Toyota's material innovation reduces environmental footprints and promotes resource efficiency.

Case: Product application of PET bottles collected in-house

■ PET bottles disposed within the company are separated, washed, and collected as clean bottles. The bottles are then recycled into high-quality materials in cooperation with related companies. The material is scheduled to be used for the outer layer of seat coverings in the Land Cruiser 250 and selected Japan-made models to be launched in the future.



Picture 1. Product application of PET bottles collected in-house [21].

(3) Waste Reduction and Management: Toyota implements rigorous waste management practices across its operations. The company strives for zero waste to landfill, optimizes resource usage, and recycles or repurposes waste materials, contributing to a more sustainable and circular value chain.

Case of water use reduction

Case: Reduction of water use through the effective use of evaporated water

Toyota Motor Manufacturing Poland SP.zo.o (Poland)

■ Efforts currently being implemented to reduce energy use as well as water use.

■ Focused on evaporated water created when reducing the volume of liquid waste (coolant, water containing oil,

wastewater from cleaning, etc.) from each process.

⇒ Evaporated water is stored in a tank and reused as makeup water for coolant.

■ Employees within the company are implementing kaizen activities.

2022 Achievements

• Water use: reduced by 720 m3 per year

• Water used in the engine process: reduced by 9% (compared to 2021) [22].

(4) Remanufacturing and Refurbishing: Toyota is an industry leader in remanufacturing and refurbishing automotive parts. Through these processes, components are restored to their original condition, extending their lifespan and reducing the need for new materials. This not only conserves resources but also reduces manufacturing costs and waste.

Case of Toyota Camry Hybrid batteries repurposing

Even after they're no longer suitable for their original purpose, the battery packs from hybrids and electric cars can still be useful. Battery energy-storage capacity diminishes over time, to the point where packs are no longer suitable for use in cars. But after their automotive service lives are finished, hybrid battery packs often still have enough usable capacity for other applications.

Like, for example, powering a cluster of buildings in a remote part of Yellowstone National Park. Packs from used Toyota Camry Hybrid batteries will now store energy generated from solar panels at the Lamar Buffalo Ranch field campus within the park.

The system includes 208 Camry Hybrid nickel-metal-hydride battery packs recovered from Toyota dealers, providing a total of 85 kilowatt-hours of storage capacity. Each hybrid battery pack was disassembled and tested before being converted for stationary energy-storage use. The hybrid battery packs were augmented with battery-management systems from Indy Power Systems, re-wired in parallel, and arranged into arrays of 52 packs each.

The solar array used to power Lamar Buffalo Ranch's five buildings generates enough electricity annually to power six average U.S. households, Toyota says. Adding onsite battery packs makes the most of solar power by storing energy for when sunlight isn't available--making for a more dependable source of power.

Micro-hydro turbines--which capture energy from a nearby stream--will be added to the site in 2016 as well. It's also possible to recycle batteries--Toyota has its own recycling program--but repurposing them can have added benefits.

Anticipated growth in the energy-storage business could mean there will soon be significant demand for battery packs to pair with solar arrays. While the nickel-metal-hydride packs used in Toyota hybrid batteries contain precious metals, the higher-capacity lithium-ion cells in electric cars are made from relatively cheap stuff.

Picture 2. Solar panels for solar power generation [23].

(5) Sustainable Supply Chain Management: Toyota integrates circular principles into its supply chain management. By working closely with suppliers, the company ensures the responsible sourcing of materials and promotes the use of recycled and renewable resources, thereby enhancing the sustainability of its products.

TMC adopted Green Purchasing Policy where:

■ TMC asks all tier 1 suppliers, including new suppliers, to implement basic initiatives based on the

TOYOTA Green Purchasing Guidelines (the “guidelines”), and also deploy and enlighten the guidelines to all tier 2 and subsequent suppliers so that the guidelines will take root.

■ Asks through the guidelines that initiatives be taken toward reducing the environmental footprint at each company’s production plants and throughout the product life cycle, and that related legal compliance be ensured, prioritizing the purchase of parts, materials, equipment and services with a low environmental footprint when manufacturing products

■ Cases of regional Green Purchasing Policy - Asks the purchasing base in each region to implement the guidelines in line with local conditions and make continuous efforts.

Case: Toyota Motor North America (North America)

Updated the existing guidelines and issued the Green Supplier Requirements in April 2021, and reinforced environmental management by including compliance with requirements (CO2 emission reductions) in the terms and conditions.

(6) Research and Development: Investment in research and development is a cornerstone of Toyota’s circular strategy. The company explores and develops new materials, technologies, and processes that enhance resource efficiency, reduce environmental impact, and contribute to a closed-loop production cycle.

Case: Recycling of Magnets

Magnets used in HV motors include two types of rare earth elements, neodymium and dysprosium. Toyota is working on the research and development of motors that use as little rare earths as possible, and it recycles the extracted neodymium and dysprosium into new magnets in cooperation with Shin-Etsu Chemical Co., Ltd.

Furthermore, they have started Car-to-Car recycling system that enables magnets to be recycled into additives for catalysts in collaboration with Sanwa-yuka Industry Corporation [24].

3.2. Recycling Resource Supply and Resource recovery

CE aims to keep materials and products within the economy—and out of landfills, incinerators, and the environment—through design for and implementation of a range of end-of-life (EoL) alternatives including recovery processes. Figure 2 displays how these mechanisms can close the life cycle of products and materials. Inner circles should be prioritized as they maintain the current value of materials longer, provided that they require less energy and resources to process.

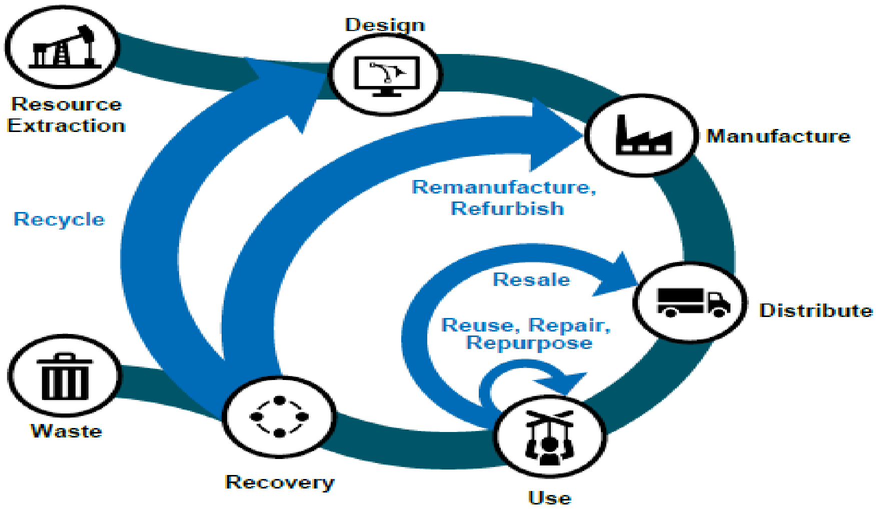


Figure 3 Circular economy system diagram displaying several major mechanisms to close the life cycle of materials and products [25]

(1) End-of-Life Vehicle Recycling: Toyota has established comprehensive programs for recycling end-of-life vehicles. The company recovers and recycles materials, components, and parts, ensuring that the environmental impact of vehicle disposal is minimized.

Toyota Global Car-to-Car Recycle Project

A Resource Recycling Initiative that Considers the Entire Vehicle Life Cycle

■ Toyota Motor Corporation works on reusing waste and recycling end-of-life vehicles to improve resource efficiency while reducing the generation of waste in each of the four stages of the vehicle life cycle: development & design,

production, sales & services, and disposal.

Usage of recycled plastic

■ In the lead up to 2050, Toyota aims to build a society that maximizes plastic recycling on a global scale.

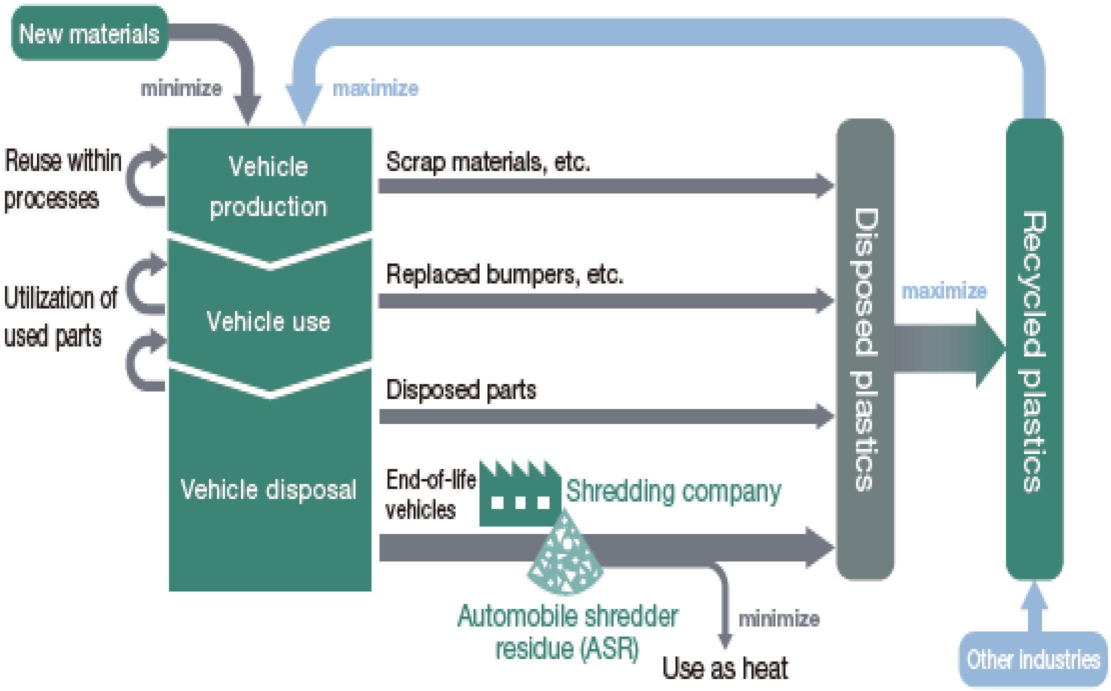


Figure 4. Maximization of Utilization of Recycled Plastics in Toyota Motor Corporation Vehicles [21]

■ They collect and recycle bumpers replaced during repairs at dealers.

■ To reuse automobile shredder residue (ASR) from end-of-life vehicles also as a material, which until now has been reused as heat, we 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.

2022 Achievements

• Gradual expansion of recycled plastic use, starting from the Prius in December 2022 (vehicles produced in Japan)

• Index for recycled plastic use in vehicle produced in Japan remained at 0.7 times, and will further expand the range of vehicles and parts using recycled plastics in the future.

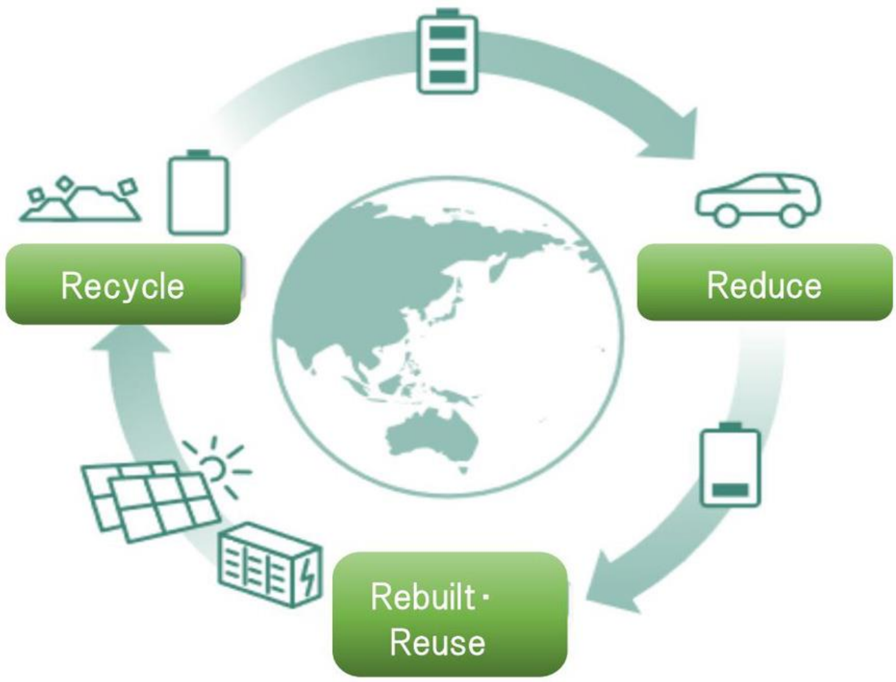
• Index for recycled plastic use in vehicles produced in Europe increased by 1.4 times.

(2) Battery Recycling: With the increasing adoption of hybrid and electric vehicles, Toyota focuses on battery recycling. The company has developed technologies and processes to efficiently recover valuable materials from used batteries, supporting a closed-loop system.

As electrified vehicles become more widespread, Toyota Motor Corporation (Toyota) is promoting activities that focus on the creation of a circular economy, including a circular ecosystem for the batteries used in its vehicles, in accordance with the broader aim of achieving carbon neutrality.

Circularity is important when considering the stages of life for automotive batteries and even more so when considering the batteries used for battery electric vehicles (BEVs). Toyota's efforts in this space include developing batteries that are resource-efficient and long-lasting during their first phase of life, so that customers can have peace of mind as they drive their cars over their term of ownership. After that, the batteries can find a second life in either automotive or non-automotive applications through reuse by repackaging (rebuilding) for the envisioned use conditions. Finally, when it is determined that they have reached their end-of-life stage, the company aims to recycle them in a sustainable way that both mitigates the amount of CO2 emitted and allows as much material as possible to be used as stock feed for new battery production.

To represent the path of circularity, the company uses the so-called "Battery 3R" and is now accelerating efforts related to what the three "R's" represent—① Reduce, ② Rebuilt/Reuse, and ③ Recycle—globally, in collaboration with various partners, and considering the availability of local battery production in each country and region. Toyota hopes the efforts not only support vehicle development but also contribute to local communities.



Picture 3. Battery 3R Image [26]

① Reduce

Reduce waste generation, including extending battery life.

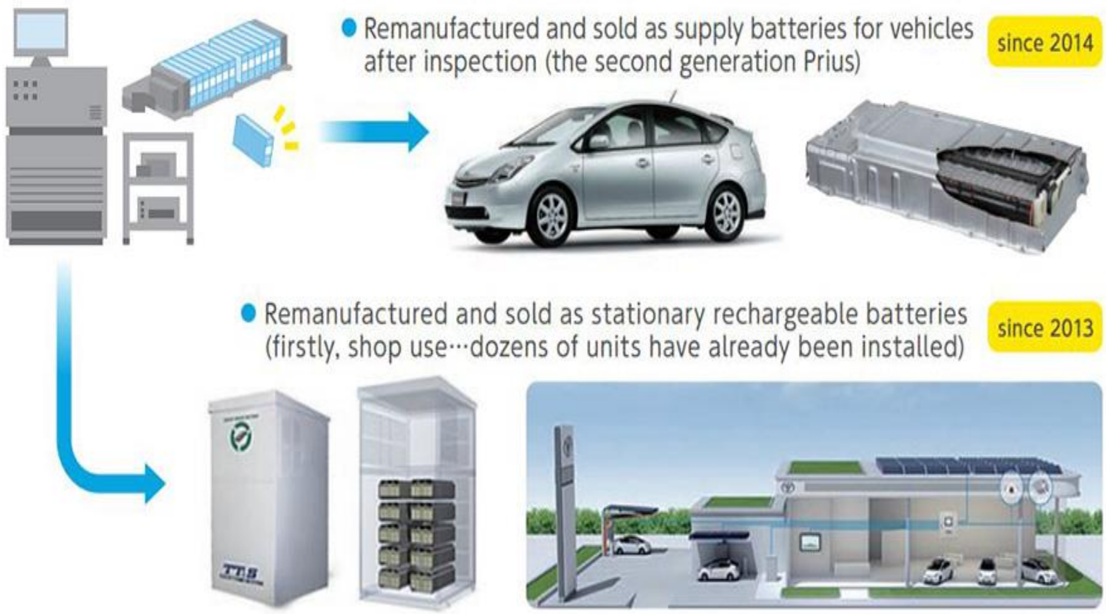
② Rebuilt and Reuse

Rebuilt - 2nd life as automotive batteries

Reuse - Reuse the batteries in non-automotive applications (e.g., stationary, energy management, etc.)
③ Recycle
Find use as recycled materials and resources
Battery 3R is part of a broader environmental strategy that Toyota is employing around the globe. Toyota is emphasizing the implementation of various initiatives related to the development of its vehicles worldwide starting from the design stage, such as resource recycling, improving the durability and longevity of products, and minimizing waste.
In 2020, Toyota formulated the Seventh Toyota Environmental Action Plan—2025 Target, an incremental action plan to achieve the Toyota Environmental Challenge 2050. Under the 2025 target, Toyota is accelerating environmental initiatives, with a strong focus on two specific initiatives
Introducing and implementing Battery 3R throughout five regions—Japan, the U.S., Europe, China, and Asia.
Aiming to maximize the collection and detoxification of end-of-life batteries globally.
Examples of 3R Battery Initiatives
① Reduce
Battery Innovation
As Toyota advances its efforts toward introducing next-generation BEVs in 2026, the company is developing next-generation batteries that feature new chemistries and even new physical structures. From further improving the energy density of liquid lithium-ion batteries and adopting bipolar structures for HEVs to BEVs, Toyota is expanding its lineup to provide customers with a variety of options, from low-cost, popular batteries to advanced batteries that pursue even higher performance. [27]
Improve battery-related performance of current BEVs
For its conventional BEV models, such as the bZ4X, Toyota is working to improve the vehicles by, for example, further shortening the charging time in low ambient temperatures via improvements to the battery warm-up performance in cold weather and extending the actual driving range by reducing power consumption and optimizing air conditioning control, as seen in the Japan market [27].
② Rebuilt and Reuse
Large-capacity sweep energy storage system with batteries for BEVs
JERA Co., Inc. and Toyota constructed a large-capacity sweep energy storage system using the drive, or traction, batteries of used electrified vehicles (HEVs, PHEVs, BEVs, and FCEVs). The constructed system enables a second use of vehicle batteries with large differences in performance and capacity in a non-automotive application [28].
Development and demonstration of stationary storage battery systems
Tokyo Electric Power Company Holdings, Inc. (TEPCO HD) and Toyota developed a stationary storage battery system (1 MW output, 3 MWh capacity) that combines TEPCO's operating technology and safety standards for stationary storage batteries and Toyota's system technology for used electrified vehicle storage batteries. Toyota Tsusho Corporation and Eurus Energy Holdings Corporation installed this system at the Eurus Tashirohira Wind Farm, with a demonstration test now underway[29].
② Rebuilt and Reuse, ③ Recycle

Hybrid Battery Initiatives

Currently, Toyota inspects and reassembles (rebuilds) used nickel-metal hydride batteries removed from HEVs in the Japanese market. The batteries have been reused as stationary batteries since 2013 and for vehicles since 2014.



Picture 4 Hybrid Battery Initiatives [29].

North American Activities

With collaboration with two partners, Toyota holds nationwide Battery Recycling Network in US.

On November 16, Toyota and Redwood Materials recently announced an expanded recycling agreement that aims to create pathways for automotive batteries used in Toyota's electrified vehicles that have reached the end of their first life. An additional agreement was also entered into for Toyota to source Cathode Active Material (CAM) and Anode copper foil from Redwood's recycling activities for Toyota's future, new automotive battery production. These agreements build on the initial collaboration with Redwood announced last year for battery collection and recycling of Toyota's hybrid and battery electric vehicle batteries. The partnership with Redwood helps to serve Toyota's West Coast battery collection and recycling needs.

Furthering its mission to create a closed-loop battery ecosystem while working toward its carbon neutrality goals, Toyota and Cirba Solutions announced that it is expanding its battery recycling network with a new collaboration on December 7. With this agreement, they expect to reduce Toyota's overall end-of-life battery transportation and logistics costs by 70 percent, while also reducing transportation-related emissions. Additionally, they aim to extract critical minerals from scrap and end-of-life batteries with an expected up to 95 percent recovery rate. The partnership with Cirba will provide support for Toyota's battery collection and recycling activities in the Midwest and East Coast [30] .

(3) Packaging and Water Recycling: Toyota's commitment to recycling extends to packaging materials and water. The company employs reusable packaging solutions and invests in water recycling technologies, further diminishing its environmental impact.

(4) Component and Material Recycling: Beyond vehicles and batteries, Toyota implements extensive recycling initiatives for various components and materials. Metals, plastics, rubber, and glass are systematically sorted, processed, and reintegrated into the production cycle, contributing to resource conservation and waste reduction [31].

3.3. Life Cycle Product Design

Figure 5. Understanding the EV Battery Life Cycle [21].

They're designing a closed-loop system to help maximize sustainability. Here's how it will work.

First Use

The battery begins life inside a Toyota vehicle, but since it can outlive the life of that vehicle, it can extend its value while also decreasing its impact to the environment. So, at the end of its first use, it's tested to determine where it should go next: to be either repurposed or reused, or sent straight to recycling if necessary.

Second Use

Batteries that are still usable for a non-automotive purpose get repurposed for non-automotive use—

for instance, to power a hospital or house, or as part of sustainable energy solutions like solar and wind. If a battery isn't usable as is, it can still be refurbished and reused for a vehicle as a certified pre-owned Toyota product.

Recycle

Toyota's ultimate goal is for all batteries to get recycled, whether immediately after the first use, or after being repurposed or refurbished. This involves extracting raw materials that can make their way back into the production process.

Production

The recycled raw materials enter the manufacturing process for new, first-use batteries. This starts with the development of individual battery cells, the assembly of the full battery unit, and, finally, installation into a new Toyota vehicle [30].

4. Conclusion

The concept of the Circular Economy is a growing focus area which, although it is not a new concept in Japan, is one that can be more widely disseminated and implemented. As laid out in this report, governments at a global level and national levels have already applied an extensive policy frameworks and guidelines centered around the concept of a Circular Economy.

At a global level, the International Organization for Standardization (ISO) is the leading international organization developing management standards that will be instrumental to supporting a CE. The new ISO Technical Committee (TC) 323 on Circular Economy is working on the principles and a framework for how to define and manage CE globally. Moreover, governments are developing their standards and rules to support and foster CE. In Japan at the national level there are three main governmental bodies that are involved in the accelerating CE in all sectors of economy: Ministry of Environment, Ministry of Economy, Trade and Industry, Japan Business Federation. Along with them, multinational corporations, associations and alliances are striving to step forward CE practices adoption. And a company level: manufacturing companies are also striving to foster a transition to CE. With Toyota company case we can see that manufacturing firms try to set their goals and strategies according to the Ellen MacArthur Foundation's three guiding principles which can be used to implement the circular economy:

1. Design out waste and pollution
2. Keep products and materials in use
3. Regenerate natural systems

In this report we could analyzed the current sustainable and circular practices of Toyota Motor Corporation. As Toyota, the globally acclaimed automobile manufacturer, has continually demonstrated leadership not only in producing high-quality vehicles but also in championing sustainable practices. From Toyota company case we can see that they start adoption circular practices from Design stage: they design vehicles with an easy- to dismantle concept, prioritizing parts and materials that can be used again. Next important stage is resource efficiency and decreasing cost of production: by recycling things, they do not use as many new resources or materials to make new ones. They use recycled materials to help make new cars and look for ways to recycle components from vehicles, such as parts from hybrid powertrains. Besides, expanding the lifetime of vehicle parts are becoming more crucial, for example the number of used batteries of electric vehicles is increasing and companies are working on their lifespan. There are more than thousand parts included in vehicles that should be recycled or utilized in a proper way. That means there are still many opportunities to do many new innovations regarding circularity and automobile companies are continuing to employ circular practices.

Acknowledgments

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Game Models to Study Competition Between Reverse Supply Chains with Traditional and E-channels

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Abstract

The concept of the circular economy, developed in the 1970s, emphasizes maximizing resource efficiency by promoting recycling and remanufacturing to reduce waste. Given resource scarcity and environmental regulations, supply chains embrace these practices to enhance sustainability. This study delves into the competition between two types of supply chains in the context of reverse logistics: the hybrid supply chain, which utilizes a dual-channel setting including traditional and E-channels for collecting used products, and the traditional supply chain, which relies solely on traditional channel for this purpose. Both supply chain models are actively involved in remanufacturing and recycling used products, and each considers different policies, including incentive-based policies, advertising investments, acceptance returns quality level, returns processing time, and transportation costs to enhance their performance. Competition models have been used to analyze optimal incentives, return rates, and profitability under game-theoretic scenarios, such as Nash equilibrium and Nash-Stackelberg leadership structures. The findings indicate that a hybrid supply chain generally demonstrates higher return rates and profitability, highlighting the success of its dual-channel structures and associated policies. Regarding economic goals, both supply chains achieve the highest profits under Nash-Stackelberg traditional supply chain leadership. However, for environmental goals, the traditional supply chain prefers the Nash scenario to achieve the highest return rates, while the hybrid supply chain prefers the Nash-Stackelberg traditional supply chain leadership. Sensitivity analysis is conducted to assess how varying parameters affect the performance and profitability of both supply chains, providing valuable insights for optimizing policy integration and supply chain management.

Keywords: Circular Economy; Smart Cities; Reverse Supply Chain; Game Theory; Collecting Channels; Re-manufacturing

1. Introduction

Circular Economy (CE) aims to optimize resource usage, minimize waste, and extend product life cycles, thereby supporting sustainable development needs (Fan et al., 2019; MacArthur, 2013). The concept of CE has been integrated into the supply chain (SC), facilitating a transition from a linear economy to a circular model (Genovese et al., 2017). This transition impacts SC by promoting sustainability through product design focused on longevity and recyclability (Alonso-Almeida et al., 2020). In contrast to the traditional linear economy, CE emphasizes the reuse, repair, refurbishment, and recycling of existing materials and products (Kirchherr et al., 2017). At the core of this transition is Reverse Logistics (RL), a strategic process that manages the return journey of goods from the point of consumption back to the point of origin (Khan et al., 2023). This process aims to recapture value and ensure the proper disposal of used products, thereby supporting sustainability and minimizing environmental impact (Trends, 1998).

Within the RL process, products that do not meet remanufacturing standards are either recycled or disposed of, while those that do are remanufactured. Recycling involves extracting critical and valuable components from used products for production while remanufacturing refurnishes products and restores the original raw materials (Giutini & Gaudette, 2003). Much of the added value from the initial production process is thus preserved in remanufacturing, resulting in significant cost savings (Yang et al., 2018) and energy conservation (Cao et al., 2020). Combining remanufacturing and recycling further enhances SC's sustainability and operational effectiveness, as demonstrated by Dell's partnership with Goodwill (Dell, n.d.). An essential process in RL is the collection system, where an SC is responsible for collecting specific used products. This sub-process includes acquiring them from consumers, inspecting products, and transporting them to remanufacturing systems (Alkahtani et al., 2021). There are three main channels for collecting used products from consumers: traditional channel (Figure 1a), E-Channel (Figure 1b), and third-party collecting channel (Zhao et al., 2021; Matsui, 2023). In the traditional channel, retailers inspect the used devices in retail stores. Immediate incentives are paid for eligible devices, while others, which are ineligible for remanufacturing, are offered recycling without incentives (Apple, 2024). The traditional channel provides direct interaction and immediate feedback for consumers who prefer in-person engagement. On the other hand, the E-channel offers an online questionnaire to estimate initial incentives on the manufacturer's website. Products are then shipped and inspected at the inspection center. After a thorough inspection, consumers receive a final incentive offer. If they accept the offer, the process continues; if they decline, the used product is shipped back to them by the carrier. The third-party collection channel relies on external expertise and infrastructure to collect used products. However, employing a third-party company can increase overall costs and introduce potential inefficiencies in the SC compared to the E-Channel and traditional channels owned by the manufacturer (Shi et al., 2015). Therefore, this study focuses on the traditional channel and the E-Channel.

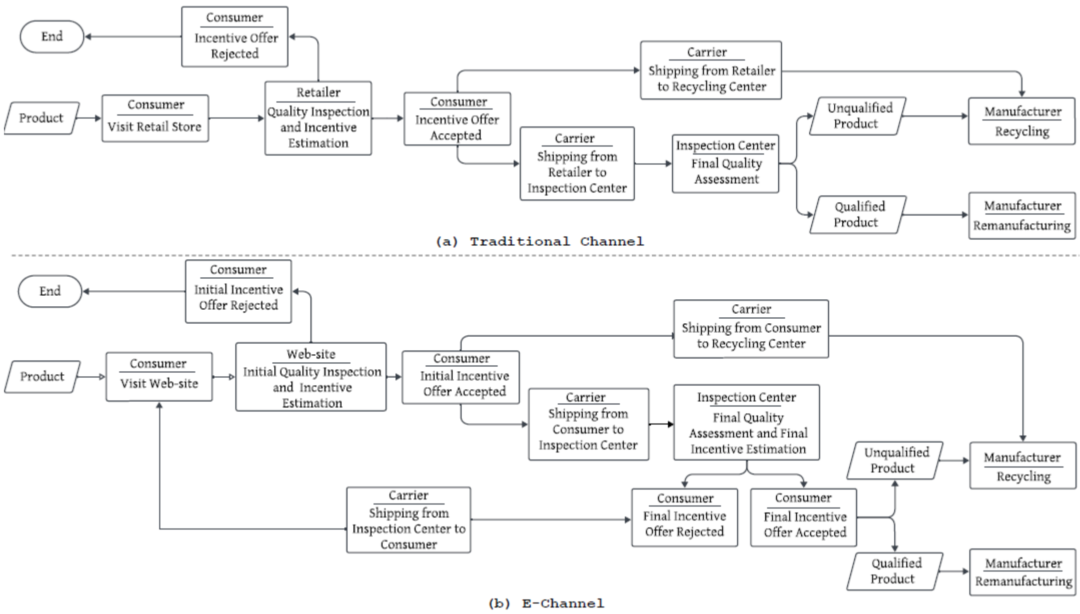

Figure 1 Traditional channel (a) and E-channel processes (b)

Five critical policies are identified as pivotal facilitators for an efficient RL channel, including (1) Price: incentive-based policies that offer discounts, credits, or other forms of compensation for returned items, effectively motivating consumers to participate in the return process (Batarfi et al., 2017; Ghoreishi et al., 2011; Hong et al., 2015; Matsui, 2023; Taleizadeh et al., 2018). (2) Quality: acceptance returns quality level for remanufacturing, an essential policy associated with profit and customer experience (Park et al., 2020). It significantly influences RL's economic and environmental values (Nikolaidis, 2013). Establishing an appropriate acceptance quality level ensures a positive customer experience while maximizing the channel's profitability through cost-effective remanufacturing (Jolai et al., 2020). (3) Advertisement: advertisement plays a critical role in encouraging consumer participation in return programs by raising awareness of the benefits of different return programs and building consumer loyalty due to their user-friendly nature (Jena et al., 2017; Ghoreishi et al., 2011; Hong et al., 2015). This increased awareness and can enhance the feasibility and profitability of RL operations (Alkahtani et al., 2021). (4) Service: transportation investments, as a component of operational expenses, have a substantial impact on the performance of collection channels and the overall profitability of the RL process (Ghoreishi et al., 2011; Mishra & Singh, 2022). Offering free shipping in E-channel is considered a consumer-friendly policy that can increase participation motivation in return programs by easing the financial burden on consumers, which can help offset its operational costs and ultimately enhance overall profitability (Jena et al., 2017). In practice, Xerox's trade-in program for used printers offers free shipping, leading to heightened customer participation and increased product returns, yielding approximately 65% in cost savings (Zhao et al., 2021; Yang et al., 2018). (5) Time: return processing times in each channel are critical for comparing different channels. This time is linked to the shipment duration, inspection, and refunding process. These processing times significantly influence customer satisfaction and benefits.

Existing studies recognize that the effects of these policies are interrelated (Ghoreishi et al., 2011;

Hong et al., 2015; Park et al., 2021). However, to our knowledge, there is a lack of an investigation of the interaction among all five policies. This study presents a comprehensive strategic model that incorporates all five policies. This model consists of two distinct two-level SCs, each comprising a manufacturer and a retailer. One SC is implemented based on a dual-channel (both the traditional channel and E-channel) for collecting used items, referred to as a hybrid supply chain (H-SC). In contrast, the other relies solely on the traditional channel, named a traditional supply chain (T-SC). The two SCs compete to improve the profit and return rate of used products for recycling and remanufacturing by offering different policies and utilizing distinct structures. To facilitate this competition, each SC has established a centralized decision-making structure that prioritizes the overall profit of the entire SC rather than individual members. This competitive environment is analyzed using game-theoretic scenarios, including Nash (peer-to-peer relationship) and Nash-Stackelberg (leader-follower relationship), to evaluate the economic and environmental performance of these SCs under different power dynamics. The economic objectives focus on maximizing profitability, while the environmental goals aim to increase returns.

The key contributions of this study are fourfold: First, the study thoroughly analyzes the competitive interactions and performances of H-SC and T-SC, utilizing the dual-channel and single-channel structures, respectively. Second, this research explores the benefits and challenges of integrating remanufacturing and recycling in SCs to further CE goals. Third, this study incorporates acceptance return quality levels, advertising investments, transportation investments, and return processing times into the incentive pricing model. This innovative approach diverges from existing literature and demonstrates the impact of these policies on SC performance. Lastly, the validity of these models is confirmed by utilizing real-world data from Apple, significantly enhancing the practical relevance and applicability of the findings.

The study's structure is organized as follows: Section 2 reviews the relevant literature. Section 3 introduces the proposed models and outlines the underlying assumptions. Section 4 presents the computational results, and section 5 includes a detailed sensitivity analysis. Lastly, Section 6 concludes with a summary of the findings and implications for future research.

2. Literature Review

The CE concept focuses on minimizing material consumption by recovering and reusing materials and products, thereby increasing efficiency in resource usage and steering consumption toward sustainability (Alonso-Almeida et al., 2020; Dincă et al., 2022). The concept of CE has been extensively applied in multiple SC research studies (Luis & Celma, 2020). The influential factors considered in these SC research studies can be categorized into RL processes, channels, and policies. Table 1 outlines a literature review focusing on channels, factors, and RL processes in SC management. Channels are categorized into traditional channels, E-channels, and third-party channels, alongside factors such as price, quality, service, and advertisement. It is worth noting that, to the best of our knowledge, the time factor has not been thoroughly explored in the existing literature. The tables also include RL processes, such as recycling and remanufacturing.

Table 1 Summary of literature review

Ref.	Channels	Policies	RL Processes
(El Saadany & Jaber, 2010)	TC /—/—	P / Q /—/—	—/ RM
(Cai, 2010)	TC / EC /—	P /—/—/—	—/ RM
(Ghoreishi et al., 2011)	TC /—/—	P /— / S / A	—/ RM
(Wu, 2012)	TC /—/—	P /— / S / A	—/ RM
(Gu & Gao, 2012)	TC /—/—	P /—/—/—	—/ RM
(Qiang et al., 2013)	TC /—/—	P /—/—/—	—/ RM
(Hong et al., 2013)	TC /—/ ThC	P /—/—/—	—/ RM
(Govindan & Popiuc, 2014)	TC/ —/—	P /—/—/—	—/ RM
(Jena & Sarmah, 2014)	TC /—/—	P /—/—/—	—/ RM
(Hong et al., 2015)	TC /—/ ThC	P /—/—/ A	—/ RM
(Fallah et al., 2015)	TC /—/—	P /—/—/—	RC /—
(Guo & Ya, 2015)	TC /—/—	P / Q /—/—	—/ RM
(Xie et al., 2015)	TC /—/—	P /—/—/—	—/ RM
(Gao et al., 2016a)	TC /—/—	P /— / S / A	—/ RM
(Jena & Sarmah, 2016)	TC /—/—	P /—/ S /—	—/ RM
(Saha et al., 2016)	TC /—/ ThC	P /—/—/—	—/ RM
(Jena et al., 2017)	TC /—/—	P /—/—/ A	—/ RM
(Xie et al., 2017)	TC / EC /—	P /—/—/—	—/—
(Batarfi et al., 2017)	TC / EC /—	P /—/—/—	—/ RM
(Feng et al., 2017)	TC / EC /—	P /—/—/—	RC /—
(Liu et al., 2017)	TC /—/ ThC	P /—/—/—	RC /—
(Taleizadeh et al., 2018)	TC / EC / ThC	P / Q /—/—	RC /—
(Taleizadeh & Sadeghi, 2019)	TC / EC /—	P /—/—/—	—/ RM
(Jolai et al., 2020)	TC /—/—	P / Q /—/—	—/ RM
(Ranjbar et al., 2020)	TC /—/ ThC	P /—/—/—	—/ RM
(Zheng et al., 2021)	TC / EC /—	P /—/—/—	—/ RM
(Park et al., 2021)	TC /—/—	P / Q /—/—	—/ RM
(Jin et al., 2021)	TC / EC /—	P /—/—/—	—/ RM
(Huang, 2022)	TC / EC /—	P /—/—/—	—/ RM
(Wang, 2022)	TC / EC /—	P /—/ S /—	—/ RM
(Matsui, 2022)	TC / EC /—	P /—/—/—	RC / RM
(Matsui, 2023)	—/ EC / ThC	P /—/—/—	RC /—

Channels: traditional channel (TC) / E-channel (EC) / Third-party channel (ThC); Policies: Price (P) / Quality (Q) / Advertisement (A) / Service (S); RL Processes: Recycling (RC) / Remanufacturing (RM); —: not included in this study.

RL is the core of these practices, significantly enhancing SC's sustainability by effectively managing product returns and reusing materials (Genovese et al., 2017). Existing studies highlight the transition from traditional linear models to achieve more sustainable practices utilizing RL (Khan et al., 2023; Mimouni et al., 2015). RL begins with collecting used products from consumers and managing end-of-life items through recycling and remanufacturing (Dhakal et al., 2017). Recycling and remanufacturing are distinct processes that aim to reduce waste and conserve resources by extracting valuable components, reusing, and repairing them (Modak et al., 2023). Incorporating both remanufacturing and recycling within an SC can further optimize resource utilization and enhance the SC's environmental performance. However, as summarized in Table 1, the simultaneous consideration of both processes has been overlooked.

One essential process in RL is the collection system, including traditional, E-channel, or dual channel, which may be influenced by factors such as SC members' preferences (Savaskan et al., 2023), consumer preferences (Feng et al., 2017; Wang, 2022), and the preferences of both consumers and SC members (Huang, 2022; Kurata et al., 2007; Taleizadeh & Sadeghi, 2019). The effectiveness of single or multi-channel structures on the operational efficiency and profitability of SCs has been intensively investigated in studies (Gao et al., 2016b; Giri et al., 2017; Zhao et al., 2021). Studies have indicated that dual-recycling channels, involving an E-channel or third-party channel alongside the traditional channel, outperform single-channel approaches in terms of profitability (Feng et al., 2017; Gan et al., 2017; Hong et al., 2013; Zheng et al., 2021). Specifically, a dual-channel strategy provides flexibility and improvements in profitability by effectively handling and reselling returned items, compared to a single-channel strategy (Batarfi et al., 2017).

Employing different policies in channels substantially impacts the effectiveness and environmental sustainability of SCs, influencing consumer behavior regarding the return of used products (Alkahtani et al., 2021). The policies can be considered in four fields: price, quality, service, and advertisement, as detailed in Table 1. Incentive-based policies seek to stimulate consumers to return used products by offering rewards or benefits. This policy has been extensively studied, as summarized in Table 1, to show its effect on enhancing consumer engagement, increasing return rates, and overall SC performance. For instance, (Taleizadeh et al., 2017) demonstrate that optimal incentive significantly influences product returns, driving sustainable operations. Returns are encouraged by higher incentives, ensuring a steady supply of remanufacturable materials and improving profitability. In the context of competition and channel differentiation in reverse SC, the significance of optimal incentive decisions for maximizing profits has been investigated (Matsui, 2022, 2023). Together, these studies provide a framework for optimizing incentive pricing in both traditional and E-channels. In the context of competition between SCs, the positive influence of offered incentives by each chain and its competitors has been illustrated by (Taleizadeh & Sadeghi, 2019). Furthermore, the effectiveness of contract-based optimal incentive decisions in a reverse SC with dual recycling channels has been suggested by (Jin et al., 2021; Saha et al., 2016) to maximize profits.

Inspecting the acceptance quality level of returned items for remanufacturing can influence SC's economic and environmental outcomes (El Saadany & Jaber, 2010). The implementation of optimal acceptance quality level standards leads to improved economic and environmental outcomes by optimizing remanufactured product quality and the cost of remanufacturing processes. The low-quality returned products could increase SC's operational costs (Guo & Ya, 2015). In the context of the channel, It has been found that the dual-channel model generally benefits manufacturers by yielding higher product quality than the single-channel model (Taleizadeh et al., 2018). Furthermore, an investigation of the influence of product quality on incentives (Jolai et al., 2020) suggests that coordinated models increase incentives for high-quality products and decrease prices for low-quality items. This approach aims to maximize profits by prioritizing higher-quality returns.

Encouraging product returns through advertising is an efficient strategy for increasing consumer awareness and improving return rates (Alkahtani et al., 2021). While previously mentioned research has mainly focused on pricing incentives and product quality, advertising investment must also be considered a critical policy for increasing return rates (De Giovanni & Zaccour, 2014). Studies by (Dridi & Ben Youssef, 2015; Hong et al., 2015; Jena et al., 2017) highlight the positive influence of advertising investments on profit and return rates in RL. Additionally, Xie et al., (2017) highlights the effectiveness of coordinated advertising investments in enhancing recycling rates and maximizing SC profits. Also, the positive effects of optimal advertising investments on product return rates and profit maximization have been emphasized (Ghoreishi et al., 2011).

Game-theoretic models are practical tools for analyzing and solving optimization problems in competitive environments (Dridi & Ben Youssef, 2015). Numerous research studies have delved into the importance of strategic game-theoretical models in competition among SCs (Giovanni & Zaccour, 2019; Jin et al., 2021; Matsui, 2023; Ranjbar et al., 2020; Wang, 2022; Wei & Zhao, 2015; Yang & Xu, 2019). Considering competition, strategic interactions, cooperation mechanisms, power dynamics, and policy impacts within SCs are essential factors in applying game theory to SCs' competitions (Shekarian, 2020). Understanding the power dynamics of leadership and followership in this context is essential for optimizing policies, improving profitability, and managing power imbalances. This power dynamic shapes the competitive landscape and determines the response of SCs to market changes and competitors (Li et al., 2018). This power dynamic can be implemented when the competition is within SC members, within competitive SCs, or encompassing both SC members and the entire SC (Fallah et al., 2015). Real-world market competitions can be modeled based on implementing these power structures, such as Stackelberg leadership between companies with different powers (local and global markets) or Nash equilibrium between two competitors with the same power (two local restaurants) (Taleizadeh & Sadeghi, 2019). In some cases, the highest profit could be achieved for all members under the Nash scenario (Jin et al., 2021), while in others, leadership scenarios are more favorable in terms of profitability (Gao et al., 2016a; Huang & Wang, 2017; Ranjbar et al., 2020).

Building on game-theoretic models, this study examines the impact of power structures on SCs' performances by analyzing leadership dynamics and their influence on pricing decisions, return rates, and overall performance. This method enables us to understand how the strategic interactions between SCs affect their ability to achieve economic and environmental objectives.

3. Model Configuration

This study delves into the competition between two SC models, T-SC and H-SC, with different structures and policies. Structural differences between these competitive SCs are illustrated in Figure 2. These policies present unique benefits and drawbacks from both consumer and SC's perspectives. Regarding acceptance quality level inspections, the H-SC involves an online questionnaire followed by a physical inspection at an inspection center to ensure thorough quality checks. Stricter quality standards are enforced for returns in the E-channel, leading to more extended returns processing time and delays in refunding consumers. These policies may have varying positive and negative impacts on customer satisfaction, return rates, operational costs, remanufactured product quality, and the overall SC's profit. On the other hand, the T-SC provides immediate reward estimations after retailer inspection, meaning the quality level inspection is less restrictive, and the processing time is much shorter. These policies can also positively or negatively impact inspection errors (which would not occur in the E-channel), consumer satisfaction, return rate, remanufacturing costs, and SC’s profit.

Advertising investments are higher in the H-SC as it leverages dual channels. In contrast, the T-SC likely benefits from lower marketing costs. Regarding transportation policies, the H-SC includes a fee for shipping products from the consumer to the inspection center and back, which positively impacts consumer satisfaction but may also negatively affect operational costs. In the T-SC, transportation is the consumer's responsibility, leading to lower operational costs but potentially lower consumer attraction. Regarding incentive policies, computational analysis is required to determine the optimal values and observe how they differ across chains. The overall effect of these policies on profitability remains uncertain. The overall impact of these policies on profitability remains uncertain. To explore this, we analyze the profitability of each SC, incorporating these policies under different competitive game scenarios. Additionally, conducting sensitivity analysis will enable us to assess how to effectively handle these policies to enhance the overall efficiency of the SCs.

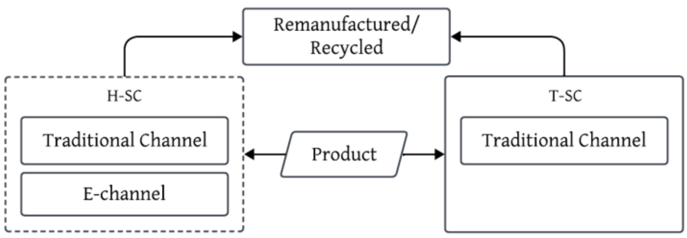

Figure 2 Structure of two competitive supply chains

3.1 Model Assumption and Notations

The table of parameters and variables is provided below (See Table 2). The upper index indicates the type of SC, and the lower index denotes the kind of channel. For instance, A_t^T denotes the cost of advertising investment for the traditional channel in a T-SC.

Table 2 Description of parameters and decision variables

Parameters	Description
A	Advertising costs
H	Acceptance returns quality level respectively from the retailer's/manufacturer's point of view.
L	Shipping cost to the inspection center
T	Returns processing time
CL	The shipping cost from the inspection center to the consumer
Q	Quality level of returned products
Υ_f, Υ_s	The percentage of consumers who agree to recycle for free in E-channels and traditional channels, respectively.
ε	Retailer's quality inspection error
CE	Remanufacturing cost per item
CI	The unit cost of inspection of the returned items through traditional channel/E-channel
CIo	The unit cost of inspection for the returned items through the traditional channel (at the final inspection center)
CT	Shipping cost from each channel to the inspection center
BR	Net profit of recycling for each item (recycling income - recycling cost)
RA	The acceptance rate for the remanufacturing process
Gmax	Maximum incentive value for used items collected by each channel
α_i	The sensitivity of the incentive value on its own (i=1) and its rivals (i=2)
τ_i	The sensitivity of the advertising investment on its own (i=1) and its rivals (i=2)
θ_i	The sensitivity of returns processing time on its own (i=1) and its rivals (i=2)
λ_i	The sensitivity of acceptance quality level on its own (i=1) and its rivals (i=2)
β_i	The sensitivity of transportation costs on its own (i=1) and its rivals (i=2)
Independent Decision Variables	
G	The optimal incentive offering by each channel to consumers in exchange for returned unit
Dependent Variables and Functions	
PRsc	Total profit of each SC
K	Return rate

To enhance the research's applicability to real-world conditions, we propose the following assumptions to reflect sensitivity coefficients better.

1. Changes in sensitivity coefficients for specific channels have a more significant impact on their own channel's return rate than the impacts arising from changes in sensitivity coefficients of competitors' channels. For example, let's consider the coefficient of incentive:

$$\alpha_{t1}^{H} \geq \alpha_{e2}^{H}, \alpha_{t2}^{T} \quad \alpha_{t1}^{T} \geq \alpha_{e2}^{H}, \alpha_{t2}^{H} \quad \alpha_{e1}^{H} \geq \alpha_{t2}^{T}, \alpha_{t2}^{H} \tag{1}$$

2. The impact of changes in sensitivity coefficients of channels on the return rate of their own channel is more significant than its influence on opposing (Chakraborty et al., 2015; Kurata et al., 2007; Mukhopadhyay et al., 2008; Taleizadeh & Sadeghi, 2019; Xu et al., 2014). Retake the coefficient of incentive as an example:

$$\alpha_{t1}^{H} \geq \alpha_{t2}^{H} \quad \alpha_{e1}^{H} \geq \alpha_{e2}^{H} \quad \alpha_{t1}^{T} \geq \alpha_{t2}^{T} \tag{2}$$

3.2 Proposed Models and Solution Methods

To calculate the return rates for each channel, we utilize a linear model that considers the positive impacts of policies within the channel and their negative influence arising from competing channels. The analysis focuses on the return rate functions for three channels: the traditional channel in H-SC, denoted as (K_t^H), the E-channel in H-SC denoted as (K_e^H), and the traditional channel in T-SC, denoted as (K_t^T). For instance, we can depict the return rate function of the traditional channel in T-SC as follows:

$$K_t^T = \text{Impacts of t channel's policies in T-SC} - \text{Impacts of t and E-channel's policies in H-SC} \tag{3}$$

Where the impact of policies within the *t* channel in T-SC includes positive coefficients representing the effects of traditional operational policies in T-SC: $\alpha_t^T \times \text{Incentive}_t^T + \tau_t^T \times \text{Advertisement}_t^T + \theta_t^T \times \text{Time}_t^T + \lambda_t^T \times \text{Quality}_t^T + \beta_t^T \times \text{Transportation}_t^T$, and the impact of policies within competing channels in H-SC encompasses negative coefficients accounting for similar operational policies in two *t* and E-channels that adversely affect the *t* channel's performance in H-SC: $-(\alpha_{e,t}^H \times \text{Incentive}_{e,t}^H + \tau_{e,t}^H \times \text{Advertisement}_{e,t}^H + \theta_{e,t}^H \times \text{Time}_{e,t}^H + \lambda_{e,t}^H \times \text{Quality}_{e,t}^H + \beta_{e,t}^H \times \text{Transportation}_{e,t}^H)$.

In this linear function, the coefficients $\alpha_i, \tau_i, \theta_i, \lambda_i, \beta_i$ indicate the influence of each policy within the channels on itself ($i = 1$) and its competitors ($i = 2$). By quantifying these influences, the model provides a comprehensive understanding of how internal strategies and external competitive dynamics collectively impact return rates. The following section outlines profit models for competitive SCs, categorizing costs associated with each member under different conditions to simplify analysis.

- Costs for the manufacturer from the traditional channel, when there is no error, are:

$$MC_qTC = CE + G_t + CIo + CT_t + \frac{CI_t}{RA_t} \tag{4}$$

- Costs for manufacturers from the traditional channel when an error happens.

$$MC'_qTC = G_t + \frac{CI_t}{RA_t} + CT_t + CI_o \tag{5}$$

- Costs for manufacturer from E-channel

$$MC_qEC = CE + G_e + CT_e + \frac{CI_e}{RA_e} \tag{6}$$

- Cost for manufacturer from the traditional channel (non-qualified, recycling)

$$MC_{q'}TC = \gamma_s \times (CT_t) \tag{7}$$

- Cost for manufacturer from E-Channel (non-qualified, no recycling)

$$MC_{q'}EC = CT_e + (1 - \gamma_f) \times CL \tag{8}$$

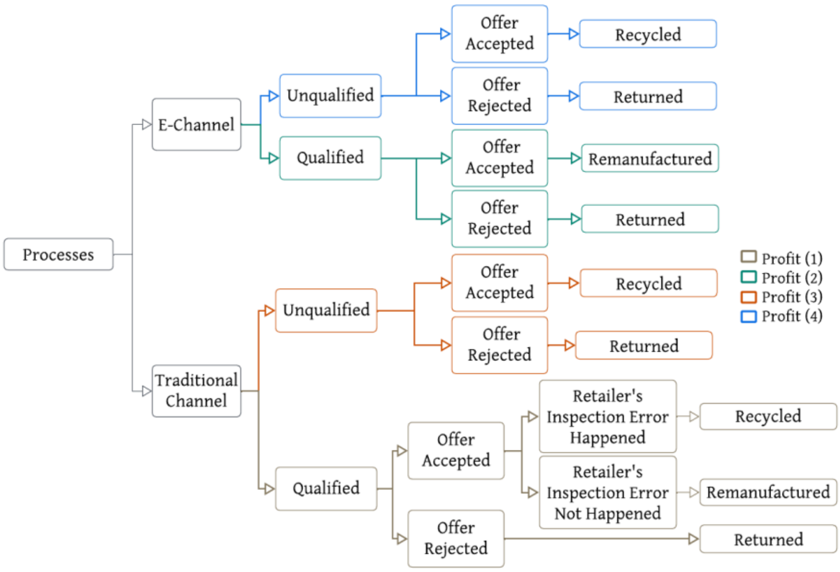

Figure 3 Operational procedures and their related profits within each channel

The flowchart of the formation of the total profit function is presented, which includes four main processes, each representing a distinct operational pathway. These processes are defined by the following equations, which outline their contribution to $PRsc^H$ and $PRsc^T$, taking into account various factors such as the number of products (N), returns acceptance quality level (Q), acceptance rates (RA), the consumer acceptance rate for recycling (γ), channels' return rate (K), incentive value (G), inspection error rate (ε), and cost and price parameters (P, BR, A, CI, CE, CT, and CL).

$$\text{Profit (1)} = N \times Q \times RA_t \times K_t \times (1 - \varepsilon_t) \times (P - MC_q TC) + \varepsilon_t \times RA_t \times K_t \times (BR - MC'_q TC) \quad (9)$$

$$\text{Profit (2)} = N \times Q \times RA_e \times K_e \times (P - MC_q EC) \quad (10)$$

$$\text{Profit (3)} = N \times (1 - Q) \times RA_t \times K_t \times (\gamma_s \times BR - MC'_q TC - CI_t / RA_t) - A_t \quad (11)$$

$$\text{Profit (4)} = N \times (1 - Q) \times RA_e \times K_e \times (\gamma_f \times BR - MC'_q EC - CI_e / RA_e) - A_e \quad (12)$$

We define the profit functions as follows:

$$PR_{sc}^{H} = \text{Profit (1)} + \text{Profit (2)} + \text{Profit (3)} + \text{Profit (4)} \quad (13)$$

$$PR_{sc}^{T} = \text{Profit (1)} + \text{Profit (3)} \quad (14)$$

3.3 Scenarios

In this section, three scenarios, including Nash equilibrium, Nash-Stackelberg with H-SC leadership, and Nash-Stackelberg with T-SC leadership, are investigated.

3.3.1 Nash

Nash equilibrium occurs when all competitors have equal influence in the market and act as players with the same power, simultaneously choosing their strategies Figure 4 illustrates the decision-making structure within this scenario.

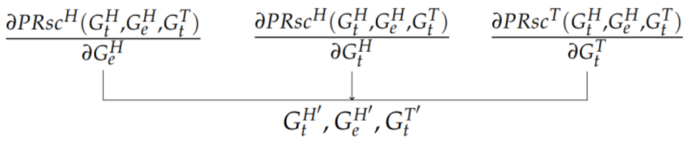

Figure 4 Decision-making structure under the Nash scenario

Proposition 1. the function $PRsc^H$ is concave with respect to G_t^H and G_e^H. See Appendix A for the proof. As the profit function of H-SC is concave, the best decisions regarding G_t^H and G_e^H to maximize H-SC's profit can be accurately determined by setting the first derivatives of $PRsc^H$ with respect to G_t^H and G_e^H to zero.

$$G_t^{H'} = \frac{\partial PRsc^H}{\partial G_t^H} = 0 \qquad G_e^{H'} = \frac{\partial PRsc^H}{\partial G_e^H} = 0 \tag{15}$$

For the optimal reward of T-SC's traditional channel, **Proposition 2.** states that the function of $PRsc^T$ is concave over G_t^T. See Appendix B for the proof. Given the concavity of the T-SC profit function, we obtain a unique optimal value of G_t^T by setting the first-order derivative of the equation $PRsc^T$ with respect to G_t^T to zero.

$$G_t^{T'} = \frac{\partial PRsc^T}{\partial G_t^T} = 0 \tag{16}$$

3.3.2 Nash-Stackelberg Hybrid Supply Chain Leadership Scenario

In a Nash-Stackelberg game, power distribution is uneven among the players, leading to an imbalance of power. In the Nash-Stackelberg H-SC leadership, the H-SC assumes the role of the leader, while the T-SC acts as a follower. Initially, the issue is approached from the follower's perspective, after which the leader makes optimal decisions (Figure 5). The value of G_t^T is determined by the T-SC's traditional channel as the optimal response to G_t^H and G_e^H derived simultaneously under the Nash structure. Previously, it has been demonstrated that $PRsc^T$ is concave over G_t^T, therefore, the optimal reward of the T-SC is determined with respect to G_t^T, denoted as $G_t^{T'}$. By substituting $G_t^{T'}$ into Eq.(3), we obtain the new values of K_t^H and K_e^H (return rates), labeled as $K_t^{H''}$ and $K_e^{H''}$, respectively. Integrating $K_t^{H''}$ and $K_e^{H''}$ into Eq. (13), we derive an updated profit function, denoted as $PR_{sc}^{H''}$. At this stage, it needs to be proven that the function $PR_{sc}^{H''}$ is concave over G_t^H and G_e^H, which has been demonstrated in **Proposition 3.** (Proof: see Appendix C). Since $PR_{sc}^{H''}$ is concave, we can determine a unique optimal value for G_t^H and G_e^H, denoted as $G_t^{H''}$ and $G_t^{H''}$, by setting the first-order derivative of $PR_{sc}^{H''}$ with respect to G_t^H and G_e^H equal to zero. Subsequently, after substituting $G_t^{H''}$ and $G_e^{H''}$ into the formula for $G_t^{T'}$, we can obtain the optimal value for $G_t^{T'}$.

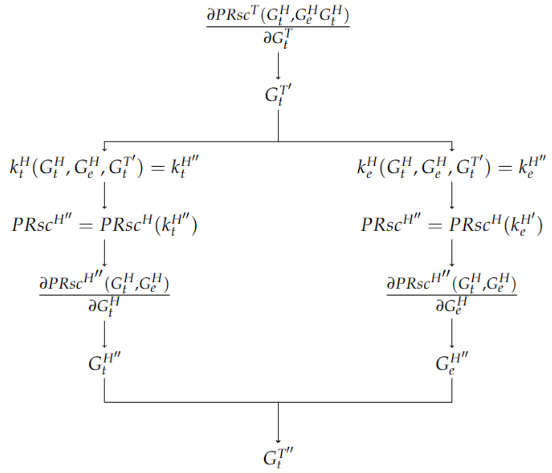

Figure 5 Decision-making structure under Nash-Stackelberg H-SC leadership scenario

3.3.3 Nash-Stackelberg Traditional Supply Chain Leadership Scenario

In this scenario, although the power distribution among the players is still uneven, the leadership role shifts to the T-SC (See Figure 6). The same Nash-Stackelberg integrated game approach is employed in the second scenario. Despite the change in leadership, the analytical process, which involves solving from the follower's perspective before the leader finalizes their strategy, remains consistent. Consequently, after substituting $G_t^{H'}$ and $G_e^{H'}$ into Eq. (3) and deriving $K_t^{T'''}$ as an updated return rate function and integrating it into Eq. (14) we establish a new formula for the profit of the T-SC, denoted as $PRsc_T^{'''}$. After confirming the concavity of $PRsc_T^{'''}$ over G_t^T in **Preposition 4.** (Proof: see Appendix D), we would compute the optimal value for G_t^T, known as $G_t^{T'''}$, by setting the first derivative of $PRsc_T^{'''}$ with respect to G_t^T to zero. Following this, by substituting $G_t^{T'''}$ into $G_t^{H'}$ and $G_e^{H'}$, we can obtain their optimal values $G_t^{H'''}$ and $G_e^{H'''}$.

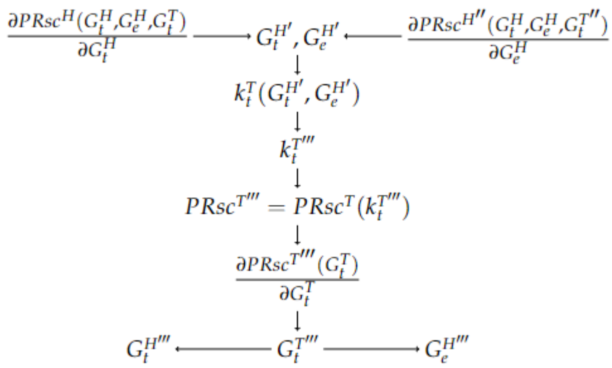

Figure 6 Decision-making structure under Nash-Stackelberg T-SC leadership scenario

4. Computational Case Study of Apple on Advanced CE Strategies

In this research, the competition models are applied to the data gained from a real-world Apple Inc. as the case study. The data utilized is sourced from Apple websites and prior studies by (Govindan & Popiuc, 2014; Taleizadeh & Sadeghi, 2019). This study focuses on Apple's GiveBack trade-in program, which allows consumers to return their used devices to Apple or any other brand for remanufacturing or recycling. The analysis covers five types of Apple iPhone devices. The results of two competitive SCs' performance metrics in various scenarios are illustrated below.

4.1 Incentives

Figure 7 illustrates that H-SC offers higher incentive values than T-SC under all scenarios, with the highest value obtained under the Nash scenario. For further insight into the analysis, **Table 3** shows the optimal incentive values of each channel. The findings demonstrate that, regardless of the power structures, the E-channel in the H-SC consistently offers more incentives than traditional channels. The T-SC's traditional channel offers more modest incentives even when assuming a leadership role. Also, H-SC's traditional channel has suggested the lowest incentive under all scenarios. The maximum incentive values of all three channels have been offered under the Nash scenario. To understand the rationale behind these decisions and their potential outcomes, it is essential to conduct further analysis of return rates, profit outcomes, and sensitivity analysis of the policies employed.

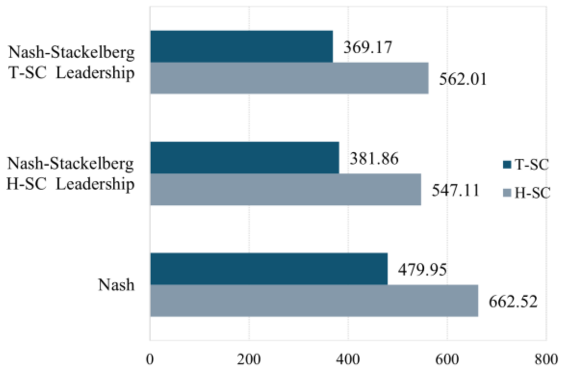

Figure 7 Optimal incentive value in H-SC and T-SC under different scenarios

Table 3 Optimal average incentive values for each product within different channels ($ per unit)

Scenario	Incentive	Product 1	Product 2	Product 3	Product 4	Product 5
Nash	G_e^H	156.74	183.60	195.37	192.82	244.88
	G_t^H	82.46	72.90	67.48	62.12	66.70
	G_t^T	102.81	97.32	93.11	86.03	100.70
Nash-Stackelberg H-SC Leadership	G_e^H	150.45	167.73	169.65	160.67	214.65
	G_t^H	75.99	55.53	39.08	26.96	33.54
	G_t^T	98.78	83.72	69.53	56.30	73.56
Nash-Stackelberg T-SC Leadership	G_e^H	152.33	170.15	172.25	163.82	218.73
	G_t^H	78.14	58.29	42.08	30.35	37.93
	G_t^T	97.14	81.53	67.20	53.48	69.85

4.2 Return Rates

As shown in Table 4, the total return rate in the H-SC exceeds that of the T-SC under all scenarios. Upon closer examination of individual channels, it becomes apparent that the E-channel experiences a lower return rate than traditional channels despite offering higher incentive values. This paradox can be attributed to the channel's stringent quality-checking process, which may discourage some consumers due to the increased likelihood of rejection and longer return processing times, despite its other consumer-friendly policies, such as higher incentives, free shipments, and greater ease of access. Conversely, the higher return rate in traditional channels can be attributed to faster inspection, shorter processing times, and less stringent quality standards, which appeal to consumers who prioritize these factors over the consumer-friendly policies provided by E-channel. The maximum return rate for traditional channels occurred under the Nash scenario, where the highest incentive value is suggested. For the E-channel, it is under the Nash-Stackelberg T-SC leadership scenario.

Table 4 Return rate under different scenarios

Scenario	K_t^H	K_e^H	K_t^T	Total K^H	Total K^T
Nash	37.00%	22.80%	40.20%	59.80%	40.20%
Nash-Stackelberg H-SC Leadership	34.28%	28.35%	37.37%	62.63%	37.37%
Nash-Stackelberg T-SC Lead	34.46%	28.50%	37.04%	62.69%	37.04%

4.3 Profit

The profit analysis in Table 5 reveals that the H-SC generates significantly higher profits than the T-SC, indicating the superiority of the H-SC dual-channel structures and offered policies. The highest profit for both H-SC and T-SC arises under Nash-Stackelberg T-SC leadership, when T-SC acts as a leader. Although T-SC experiences a significantly increased return rate in Nash, its total profit is the lowest under this scenario, which might imply that despite high return rates, the associated costs or operational inefficiencies reduce profitability. In contrast, the highest return rate for the E-channel is also obtained under Nash-Stackelberg T-SC leadership, suggesting an increasing relationship between H-SC's return rate and overall profit. A comprehensive sensitivity analysis should examine the interplay between these policies and their impact on profitability.

Table 5 Profit across different scenarios (billion $)

Scenario	Profit	Product 1	Product 2	Product 3	Product 4	Product 5
Nash	$PRsc^H$	101.323	80.2032	56.6943	75.4965	111.239
	$PRsc^T$	54.8832	44.986	30.6644	44.6155	66.7623
Nash-Stackelberg	$PRsc^H$	100.091	77.7913	54.0021	71.6727	107.275
H-SC Leadership	$PRsc^T$	55.0541	42.26	30.97	45.08	67.24
Nash-Stackelberg	$PRsc^H$	100.844	80.1214	56.8909	75.8301	111.278
T-SC Leadership	$PRsc^T$	55.4401	45.6827	31.3361	45.6277	67.9116

5. Sensitivity Analysis

Sensitivity analysis is crucial for understanding how different policies affect the performance of H-SC and T-SC models. The one-at-a-time (OAT) method is used to systematically vary each policy within a feasible range and observe its effects on performance metrics.

5.1 Policies

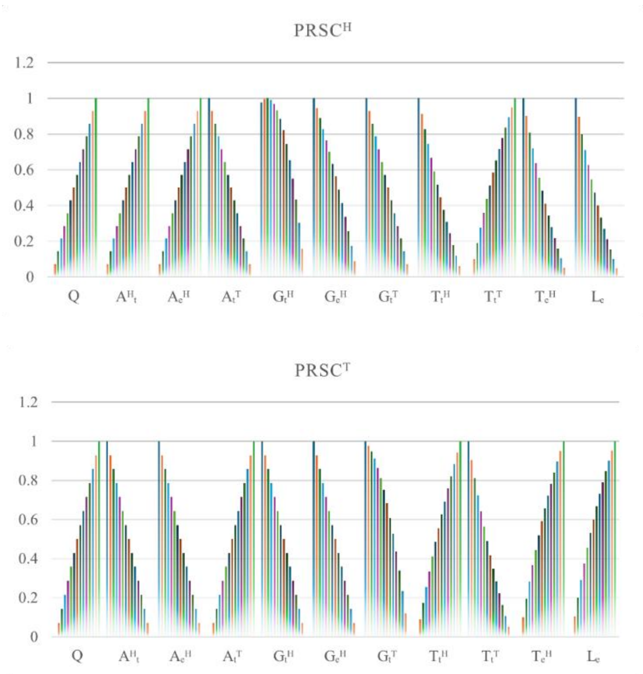

Figure 8 Analysis of changes arising from variations in each policy

The analyses are conducted for both SCs within the Nash-Stackelberg T-SC leadership scenario, which has been identified as the most profitable scenario. Figure 8 shows the changes made by increasing each of the five policies. In summary, we observe: (1) Quality level: The higher quality returns within H-SC significantly impact profitability, likely due to reduced remanufacturing costs and improved remanufactured product quality. We observe a similar pattern in T-SC's operations. Despite benefiting from a less stringent quality control resulting in higher return rates, T-SC does not experience increased profitability as a result. Therefore, increasing the acceptance quality level, leading to higher-quality returns, is closely associated with enhanced profitability. This underscores the vital role of this process in both SCs, particularly in H-SC. (2) Advertising: Increasing advertising investments for each SC enhances its profitability. It improves customer awareness and engagement, which typically leads to greater profitability. However, this increased profitability also leads to higher operational costs, necessitating a balanced investment approach. (3) Incentive: Analyzing optimal incentives for H-SC and T-SC shows that channels respond differently to incentive changes. The E-channel in H-SC is more sensitive to increases in incentives, necessitating precise adjustments to balance customer satisfaction and operational costs. Conversely, the traditional channels in H-SC and T-SC show greater stability, maintaining nearly constant profitability across a broader range of incentives before showing a decline. This indicates that these channels can support increased incentives when needed to attract higher returns or effectively address competitive pressures. To optimize profitability, it is essential to identify and maintain incentive values within the optimal range for each channel, balancing the trade-offs between attracting returns and controlling operational costs. (4) Time: Increasing processing time in both H-SC and T-SC leads to a gradual decrease in profit with different sensitivities. The significant profit reduction in traditional channels indicates that consumers prefer these channels for faster processing, and extending processing time may prompt consumers to rethink their preferences. On the other hand, the minimal impact on profit with extended processing time in the E-channel indicates that consumers selecting this channel are less concerned about this factor. (5) Transportation: As transportation costs rise, H-SC's profits consistently decline. This indicates that increased transportation investments in H-SC's E-channel lead to diminished overall profit, as higher operating costs outweigh the advantages. It is worth noting that the graph also demonstrates that beyond a certain threshold, additional increases in transportation costs do not significantly impact H-SC's profit. This suggests an optimal range for transportation costs where further investments do not improve profitability. Maintaining transportation costs within this range can help prevent unnecessary expenses.

From the analyses, we conclude that enhancing the profitability of one SC leads to a corresponding decrease in the profits of the rival SC, highlighting the competitive dynamics at play. For instance, increased advertising spending in the SC enhances the profitability and diminishes the competitors' profitability as it attracts more consumers to the SC. This underscores the significance of strategic investments that improve SC performance and counteract the gains of the rival SC. However, this inverse relationship doesn't extend to incentives. While higher incentive values can drive up return rates, they also elevate operational costs, reducing overall profitability for both SCs. Given that, the incentive values are optimal, even slight deviations can decrease profitability. Moreover, if increasing the incentives, the rival SC may experience reduced return volumes or feel compelled to raise their incentives, leading to similar higher costs and reduced profitability. This interconnected dynamic illustrates that while higher incentives are designed to boost returns, they can significantly escalate costs for both SCs, ultimately reducing overall profitability.

5.2 Sensitivity Analysis Interpretation

We generate Pareto charts and conduct regression analysis to study model sensitivity, identifying the most effective policies and their impact on profitability. The Pareto chart analysis (Figure 9) reveals that the foremost influential factor for H-SC is Q, which significantly and positively affects profit. Additionally, vital parameters such as A_t^H and A_e^H, positively influence profit while G_t^H, G_e^H, T_t^H, and L_e negatively impacts H-SC's profitability, indicating areas for cost control. A_t^T and G_t^T policies imposed by their rival, T-SC, negatively impact H-SC's profit, showing the need for a strategic response to these competitive pressures. Similarly, for T-SC, Q remains the most impactful parameter. A_t^T shows a significant positive impact on profit, underscoring the importance of effective advertising, whereas G_t^T, T_t^T form its own chain and G_t^H, G_e^H, A_t^H, A_e^H , and T_e^H, from H-SC negatively impacts profitability, suggesting optimization opportunities. Both charts indicate that the initial policies impact profit most, with a diminishing return as more variables are considered. This analysis highlights the importance of prioritizing critical policies to maximize profit while addressing negative influences for effective strategic management in both SCs.

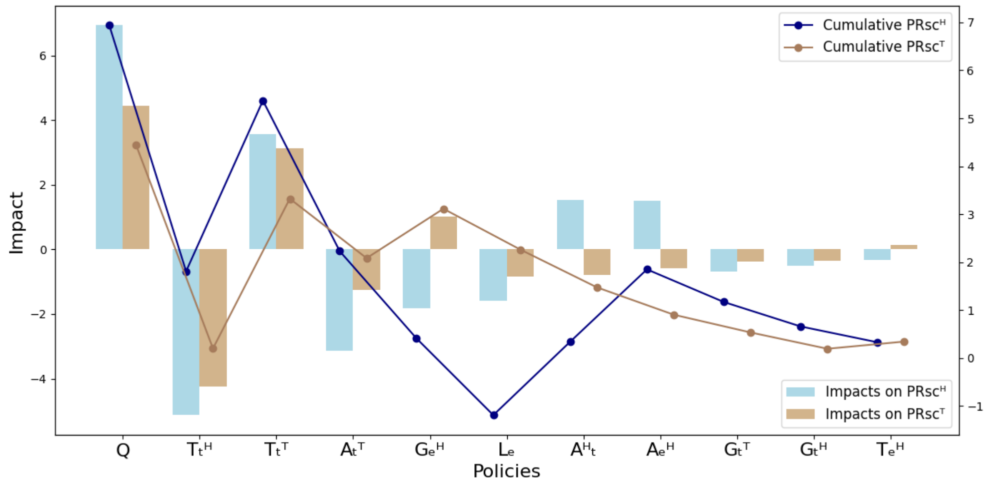

Figure 9 Impact of policies on profit: a Pareto perspective

Using the regression analysis, we conduct tables of results (See Table 6 and Table 7) showing each policy's contribution to profits, both in terms of its direct impact (coefficients) and its relative importance (weights).

Table 6 Regression results: sensitivity analysis interpretations for H-SC

Factor	Const	Q	A_t^H	A_e^H	A_t^T	G_t^H	G_e^H	G_t^T	T_t^H	T_e^H	T_t^T	L_e
Coefficient	0.30	6.94	1.53	1.51	-3.14	-0.51	-1.82	-0.68	-5.13	-0.33	3.56	-1.60
Weight (%)	-	25.67	5.66	5.58	11.61	1.88	6.73	2.51	18.98	1.22	13.17	5.91

Table 7 Regression results: sensitivity analysis interpretations for T-SC

Factor	Const	Q	A_t^H	A_e^H	A_t^T	G_t^H	G_e^H	G_t^T	T_t^H	T_e^H	T_t^T	L_e
Coefficient	0.345	3.1242	-1.24	-0.85	4.44	-0.57	-0.37	-0.79	1.03	-0.34	-4.24	0.15
Weight (%)	-	18.08	7.18	4.92	25.69	3.30	2.14	4.57	5.96	1.96	24.54	0.87

The regression analysis for H-SC and T-SC highlights that improving acceptance quality levels significantly boosts profitability, with coefficients of 6.94 for H-SC and 3.124 for T-SC, indicating that higher quality levels lead to higher profit. Advertising investments positively impact the respective SC's profitability while negatively affecting the competitor, with T-SC's traditional channel advertising having the most substantial positive effect (coefficient 4.447, 25.69% weight). Incentives need careful balancing, as increasing them reduces profitability due to higher costs, particularly for H-SC's E-channel, which already offers higher incentives (coefficient -1.82, 6.73% weight). Longer processing time, especially in traditional channels (H-SC: coefficient -5.13, 18.9% weight; T-SC: coefficient -4.24, 24.54% weight), reduce the SC's profit, while E-channels are less sensitive to these changes. Higher transportation costs also harm profitability, with a coefficient of -1.6 for H-SC. These insights emphasize strategic decisions in policies to optimize profitability in competitive SCs. The regression analysis indicates that while the E-channel's increased transportation costs enhance consumer convenience, the higher costs exceed the benefits, reducing H-SC's profitability. Based on previous findings, it's evident that this outcome would persist until a certain point. H-SC should, therefore, maintain transportation costs at an optimal level and concentrate on enhancing other policies such as processing time, quality checks, and advertising to improve profitability.

6. Conclusion

This research delves into the competition between two types of SCs, H-SC and T-SC, in the context of CE including remanufacturing and recycling used products. It employs competition models to analyze optimal incentives, return rates, and profitability within game-theoretic scenarios, such as Nash equilibrium, Nash-Stackelberg H-SC leadership, and Nash-Stackelberg T-SC leadership. It integrates CE principles with RL processes and explores various collection channels, encompassing traditional and E-channels, to provide insights into their effectiveness on SC sustainability and efficiency.

Based on the findings, H-SC demonstrates superior return rates and profitability across all scenarios, underscoring the effectiveness of its dual-channel structures and associated policies. The highest return rate for H-SC correlates with the highest profit, attributable to the efficiency and optimality of its structure and operational activities, resulting in higher-quality remanufactured products and lower remanufacturing costs. Conversely, this correlation is absent in T-SC, where higher return rates do not always lead to increased profits, primarily due to higher operational expenses related to lower-quality inspections and potential inspection errors by retailers and low-quality remanufactured products. The highest profits for both SCs are achieved under T-SC leadership, indicating that T-SC's leadership enhances overall profitability. This profit-oriented insight is particularly valuable for SCs with similar structures prioritizing economic goals. However, for SCs prioritizing environmental goals, which focus on return rates, T-SC leadership is optimal for H-SC, while the Nash scenario is most beneficial for T-SC.

The study reveals several insights when focusing on the channels. While offering higher incentives, the E-channel experiences lower return rates than traditional channels. This is due to its stringent quality-level inspection process, which can discourage consumers due to the increased likelihood of rejection and longer return processing time. These policies outweigh its other consumer-friendly policies, such as higher incentives, free shipping, and easier access. Conversely, despite providing lower incentives, traditional channels exhibit higher return rates. This can be attributed to consumers' preference for fast and less restrictive quality-level inspection and refunding processes within these channels, which are favored over higher incentives and the absence of free transportation costs. The sensitivity analysis reveals that the quality level of returns is a significant factor in the profitability of both H-SC and T-SC, contributing approximately 18% to the profitability of T-SC and 25% to that of

H-SC. Enhancing quality standards significantly boosts profits, highlighting the need for stringent quality control. Additionally, strategic advertising investments and efficient processing time management are essential for optimizing financial performance. The longer processing time for traditional channels would reduce profitability significantly due to the loss of consumers who definitely choose these channels for their fast inspection and refunding processes.

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Appendix

Proof of Lemma A

A.1 The second-order derivative of Eq. $PRsc^{H}$ with respect to G_t^H. The second-order derivative of Eq. $PRsc^{H}$ with respect to G_t^H is given by:

$$\frac{\partial^2 PRsc^H}{\partial {G_t^H}^2} = N \times Q \times (-2 \times RA_o \times \alpha_{t1}^H \times \varepsilon - 2 \times RA_o \times \alpha_{t1}^H \times (1-\varepsilon))$$

which simplifies to: $-2NQRA_o\alpha_{t1}^H$. Given that N, Q, RA_o, and α_{t1}^H are typically positive in the context of this problem (representing quantities, rates, or coefficients that are inherently non-negative), the entire expression is negative, regardless of the value of ε (provided $0 < \varepsilon < 1$). Hence, the expression is definitively negative, proving the concavity of $PRsc^H$ with respect to G_t^H

A.2 The second-order derivative of Eq. $PRsc^H$ with respect to G_e. The second-order derivative of Eq. $PRsc^H$ with respect to $G_e^H$is:

$$\frac{\partial^2 PPRsc^H}{\partial {G_e^H}^2} = -2 \times N \times Q \times RA_e \times \alpha_{e1}^H,$$

which is negative, given the positivity of N, Q, RA_e, and α_{e1}^H. This further supports the concavity of $PRsc^H$ with respect to G_e^H.

Proof of Lemma B

The second-order derivative of Eq. $PRsc^T$ with respect to G_t^T is given by:

$$\frac{\partial^2 PRsc^T}{\partial {G_t^T}^2} = N \times Q \times (-2 \times RA_o \times \alpha_{t1}^H \times \varepsilon - 2 \times RA_o \times \alpha_{t1}^H \times (1-\varepsilon)),$$

which is precisely the same as the G_t^Hin $PRsc^H$. This demonstrates that the concavity conditions for G_t^Hin $PRsc^H$ directly apply to G_t^Tin $PRsc^T$, affirming the concavity of $PRsc^T$ with respect to G_t^T.

Proof of Lemma C

C.1 The second-order derivative of $PRsc_H''$ with respect to G_t^H. The second-order derivative is:

$$\frac{\partial^2 PRsc_H''}{\partial {G_t^H}^2} = N \times Q \times \left(-2 \times RA_o \times \varepsilon \times \left(\alpha_{t1}^H - \frac{\alpha_{t2}^H \times \alpha_{t2}^T}{2 \times \alpha_{t1}^T}\right) - 2 \times RA_o \times (1-\varepsilon) \times \left(\alpha_{t1}^H - \frac{\alpha_{t2}^H \times \alpha_{t2}^T}{2 \times \alpha_{t1}^T}\right)\right).$$

The simplified expression is:

$$\frac{RA_o \times (-2 \times \alpha_{t1}^H \times \alpha_{t1}^T + \alpha_{t2}^H \times \alpha_{t2}^T)}{\alpha_{t1}^T}.$$

Given the inherent positivity of the involved parameters, this outcome, due to the subtraction operation and the negative sign, is inherently negative, indicating the concavity of $PR_{sc}^{H''}$ with respect to G_t^H.

C.2 The second-order derivative of $PRsc_H''$ with respect to G_e^H. The second-order derivative is:

$$\frac{\partial^2 PRsc_H''}{\partial {G_e^H}^2} = -2 \times N \times Q \times RA_e \times \left(\alpha_{e1}^H - \frac{\alpha_{e2}^H \times \alpha_{t2}^T}{2 \times \alpha_{t1}^T}\right).$$

The simplified expression matches the previous case, and under the given conditions, it is negative, affirming the concavity of $PRsc_H''$ with respect to G_e^H.

Proof of Lemma D

The second-order derivative of $PRsc_T''$ with respect to G_t^T is given by:

$$\frac{\partial^2 PRsc_T''}{\partial {G_t^T}^2} = N \times Q \times (-2 \times RA_O \times \varepsilon \times \left(\alpha_{t1}^T - \frac{\alpha_{t2}^H \times \alpha_{t2}^T}{2 \times \alpha_{t1}^H} - \frac{\alpha_{e2}^H \times \alpha_{t2}^T}{2 \times \alpha_{e1}^H}\right) - 2 \times RA_O \times (1 - \varepsilon) \times \left(\alpha_{t1}^T - \frac{\alpha_{t2}^H \times \alpha_{t2}^T}{2 \times \alpha_{t1}^H} - \frac{\alpha_{e2}^H \times \alpha_{t2}^T}{2 \times \alpha_{e1}^H}\right)).$$

The simplified expression for the formula is:

$$\frac{N \times Q \times RA_O \times (-2 \times \alpha_{e1}^H \times \alpha_{t1}^H \times \alpha_{t1}^T + \alpha_{e1}^H \times \alpha_{t2}^H \times \alpha_{t2}^T + \alpha_{t1}^H \times \alpha_{e2}^H \times \alpha_{t2}^T)}{\alpha_{e1}^H \times \alpha_{t1}^H}.$$

Given all parameters are positive and considering $0 < \varepsilon < 1$, the sign of this expression depends on the numerator's terms. Specifically, the numerator includes both positive and negative terms. However, the presence of a negative sign in front of the largest term, $(2 \times \alpha_{e1}^H \times \alpha_{t1}^H \times \alpha_{t1}^T)$, suggests that the expression is designed to be negative. This is unless the sum of the two smaller terms, $(\alpha_{e1}^H \times \alpha_{t2}^H \times \alpha_{t2}^T)$ and $(\alpha_{t1}^H \times \alpha_{e2}^H \times \alpha_{t2}^T)$, is greater than twice the product $(\alpha_{e1}^H \times \alpha_{t1}^H \times \alpha_{t1}^T)$, which is unlikely under normal circumstances, given the context provided. Therefore, the expression is negative under the given conditions where the coefficients are intended to signify the impact on their respective channels' return rates more than those of competitors.

Electrical and Electronics Sector

Circular Economy Policies of Japan and Case Studies of Sony Corporation

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Abstract

The circular economy policy of the government in Japan is intended to build corporate competitiveness and increase corporate value over the long term by shifting corporate economic activities to a circular model, while strengthening the 3Rs as environmental protection. In order to achieve this, the government intends to provide soft-law guidelines and milestones, but will leave it to the voluntary efforts of industry. In response to this policy, the Keidanren, Japan's largest business association, has formulated a voluntary plan for the formation of a recycling-oriented society. However, since there are a wide variety of industries, each industry association individually sets specific targets, such as the amount of final disposal of industrial waste and the amount of reduction in plastic use.

The JEITA is one of the industry members of the Keidanren, comprising companies in the information technology and electronics industries. In addition to setting its own environmental targets, the JEITA has been creating manuals for design methods that incorporate environmental impact reductions, and developing new recycling technologies, and the results of these efforts are being shared with member companies. However, the transformation of business models toward a circular economy is largely dependent on the management policies of each member company, so the current situation is that only a limited number of companies are shifting their business models toward a circular economy.

Current efforts toward a circular economy made by Sony, a leading member company of the JEITA, are mainly aimed at reducing environmental impacts, such as using renewable energy, disposing of waste, and managing chemical substances. These efforts represent an extension of the 3R initiatives that have been carried out in the past. Sony is exploring new business models for a circular economy, such as a decentralized open energy system and a symbiotic farming method; however, all these activities are still in the development stage at the research institute. When innovations in technologies, services, and new business models improve the sustainable competitiveness of the company and lead to an increase in corporate value over the long term, the circular economy policies of Japan will see fruitful results.

1. Introduction

The circular economy is an economic activity that creates added value through effectively utilizing stocks, aiming to minimize resource consumption and maximize the value of products (MOE, 2023). As global issues such as climate warming and marine plastic waste become more apparent, dealing with these environmental problems has become an unavoidable issue for governments and companies in order to continue their economic activities. On the other hand, it is also necessary to view the transition to a circular economy as an opportunity to go beyond environmental issues and build international competitiveness by increasing added value through servitization. In Japan, all parties, including the government, business associations, industry associations, and individual companies, need to work together to keep up with global trends on how to respond to the trend toward a circular economy.

This article examines the circular economy initiatives of Sony, one of Japan's leading electronics companies, and analyzes how they reflect the policies of the government, business associations, and industry associations. The electronics industry is currently undergoing a major transformation, and international competition is intensifying. In order for Japanese companies to build their competitiveness in the paradigm shift of the transition to a circular economy, the policies of the government, business associations, and industry associations must support this shift. The purpose of this article is to analyze how the government's circular economy policy shapes the policies of business and industry associations, as well as the efforts of companies operating at the forefront of economic activities.

The structure of this paper is as follows. Chapter 2 summarizes the characteristics of the circular economy policies of the Japanese government, business associations, and industry associations. Chapter 3 introduces Sony's basic policies and specific examples of its efforts toward a circular economy. Chapter 4 analyzes how the policies of the government, business associations, and industry associations are reflected in Sony's initiatives, and discusses the challenges and prospects for the future.

2. Circular Economy Policies of Japan

2-1. Policy of government I: the Ministry of Environment

The circular economy refers to a society that aims to achieve both economic development and environmental protection. While the Ministry of Economy, Trade and Industry (METI) is mainly involved in policymaking from the perspective of economic policy, the Ministry of Environment (MOE) is mainly responsible for policymaking from the perspective of environmental policy. The Basic Law for the Promotion of a Recycling-Oriented Society (Basic Law on Recycling), enacted in 2001, is a law that sets out the basic principles for the formation of a recycling-oriented society, and it clearly shows the shape of circular economy from the perspective of environmental protection (MOE, 2022). This law defines a recycling-oriented society as "a society in which the consumption of natural resources is suppressed and the burden on the environment is reduced as much as possible, which is realized by suppressing the conversion of products into waste, next by using the waste discharged appropriately, and finally by ensuring that the unusable waste is properly disposed of." In addition, priorities for the cyclical use of resources and waste disposal are statutorily enacted as (1) reduction of generation, (2) reuse, (3) recycling, (4) heat recovery, and (5) appropriate disposal.

Under the Basic Law on Recycling, the Act on Promotion of Effective Utilization of Resources concerns the recycling of resources, and the Waste Disposal Act concerns the proper disposal of waste. In addition, there are individual recycling laws (the Containers and Packaging Recycling Law, the Home Appliance Recycling Law, the Food Recycling Law, the Construction Recycling

Law, and the Automobile Recycling Law) that regulate these efforts according to the characteristics of individual items with a particularly large amount of waste. These legal systems characterize Japan's efforts to protect the environment. In addition to the role of business entities, these laws have clarified the role of consumers, which is to use products for a long time, use products with recycled resources or recycled parts, and cooperate in sorting and collection. As a result of these efforts, the amount of waste in Japan has decreased significantly, and the amount of municipal waste generated per capita has reached the lowest level in the world (MOE, 2023).

In addition, three major measures are being taken to recycle plastics. The first is the promotion of plastic resource recycling. In 2019, the government formulated a plastic resource recycling strategy, and in April 2022, the "Act on the Promotion of Resource Recycling Related to Plastics (Plastic Resource Recycling Act)" was enacted to make it concrete. The second is the introduction of bioplastics. In January 2021, the "Bioplastics Introduction Roadmap" was formulated to improve the practicality of bioplastics and promote the substitution of fossil fuel-derived plastics, outlining the basic policies for the introduction of bioplastics. It also planned actions such as support for the development of production facilities and demand stimulation through government-led procurement, etc. The third is the formulation of ESG guidance in the field of plastic resource recycling. In January 2021, the "Disclosure and Dialogue Guidance for the Promotion of Sustainable Finance in the Circular Economy" was established as ESG guidance in the field of plastic resource recycling for both investors and companies. It aimed to ensure that companies that take the lead in plastic resource recycling are appropriately evaluated by investors, and to develop a common foundation that will lead to the enhancement of their corporate value and international competitiveness.

2-2. Policy of government II: the Ministry of Economy, Trade and Industry

The Ministry of Economy, Trade and Industry (METI) announced in 1999 the "Circular Economy Vision 1999," which aims to shift from a linear economy system based on mass production, mass consumption, and mass disposal to a circular economy system that integrates the environment and the economy, and recommended the full-scale introduction of three measures (3Rs) of waste recycling, reduction of generation, and reuse of parts. The "Circular Economy Vision 2019", released in 2019, summarizes the efforts of the past 20 years, and assesses that although the 3Rs have progressed and achieved certain results such as improving the recycling rate, the transition from a linear economy system to a circular economy system is still only half complete (METI, 2020). The market in the field of waste treatment and effective use of resources has not yet become an industry that generates sufficient added value, and resource recycling as a business has not yet been fully promoted. It is emphasized that it is necessary to shift from the 3Rs as an environmental activity to economic activities based on advanced circular use of resources, that is, to a circular economy.

Specific measures to achieve this include the use of digital technology as a driver for the transition to a circular economy and the construction of a service and solution business model that utilizes AI and IoT. Some examples of such measures include subscription services that integrate products and services to provide value, advanced waste sorting using AI, and streamlining the 3Rs through logistics systems that combine IoT and big data analytics. The shift to recycling-oriented economic activities is expected to enhance the sustainability of business and become a source of competitiveness, leading to an increase in corporate value over the long term.

In addition, as the product values shift from hardware to software and services, shifting to recycling-oriented economic activities can become a new source of added value for the manufacturing industry. In other words, as hardware becomes more general purpose and added value shifts to services and solutions, it is possible to appeal value throughout the product life cycle by durability and upgradability on the premise of long-term use. Increased durability means that consumers will purchase products less often, but more maintenance, upgrades, support, and other services will be provided. By providing more value-added services over a longer period of time, it should be possible to build a profitable business model. In addition, in developing products with enhanced durability, it is also possible to take advantage of the strengths of Japan's industrial structure, which provide a "coordination" that transcends the boundaries between companies in the supply chain. In this way, companies are required to promote the shift to a highly circular business model in their management strategies, by viewing it as a new business opportunity that leads to a "virtuous cycle of environment and growth" rather than an extension of the 3Rs as environmental activities.

In doing so, the government has indicated the milestones to be achieved, minimized regulatory measures while utilizing soft laws such as guidelines, and emphasized encouraging voluntary efforts by industry. The nature of the circular economy and the methods for achieving it differ from country to country, and it is essential for companies to have the flexibility to optimize their global operations in response to individual market requirements. There is a concern that the introduction of a hard-law regulatory approach that targets only domestic business activities will lead to rigidity in firms' efforts, impede ingenuity and innovation, and cause a decline in international competitiveness. The METI believes that Japan's major strength lies in the voluntary efforts of industry and that soft-law policies are appropriate for companies to respond flexibly to changes in the global market.

2-3. Policy of business association: the Japan Business Federation (Keidanren)

Based on the government's basic policy of relying on the voluntary efforts of industry while utilizing soft laws such as guidelines, how is the business association trying to promote initiatives toward a circular economy? The Japan Business Federation (Keidanren) is Japan's largest business organization, with 1,500 major companies, and makes policy recommendations on a wide range of important issues facing the business community. In 1997, the Keidanren formulated the "Voluntary Action Plan for the Environment" on waste management (Keidanren, 2021a). It includes numerical targets for each industry and specific measures to achieve the targets, and thereafter the Keidanren follows up on the progress of each industry every fiscal year.

In 2007, the Keidanren expanded this plan and formulated the "Voluntary Action Plan for the Formation of a Circular Society" with the aim of promoting a wide range of industrial initiatives for the formation of a circular society as well as waste countermeasures. Currently, 45 industries are participating in this plan, and three types of targets have been set for each industry: (1) targets for reducing the amount of industrial waste, (2) industry-specific targets, and (3) plastics-related targets. The Keidanren conducts a follow-up survey every fiscal year and publishes the results (Keidanren, 2022).

In addition to industry-specific targets, the Keidanren has set a target of reducing the final amount of industrial waste disposal by 75% in FY2025 compared to the FY2000 level for the business community as a whole. As for the specific targets for each industry, targets are set based on the characteristics and circumstances of each industry, such as the recycling rate of by-products generated in the manufacturing process and the amount of reduction in general business waste. In addition, plastics-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.

In this way, although the Keidanren has raised the slogan of creating a circular society, the targets set across industries are related to the reduction of industrial waste and the recycling of plastic resources, and are limited to the so-called 3R initiatives. It is not yet in a position to lead a bold shift to a circular business model. In March 2021, the Keidanren established the Circular Economy Partnership in collaboration with the MOE and the METI with the aim of fostering understanding and promoting the initiatives of the circular economy (Keidanren, 2021b); however, most of the advanced initiatives introduced in its case studies and presentations are related to the 3Rs. In addition, numerical targets and specific measures to achieve those targets are based on the voluntary plans of each industry association, and the Keidanren's role is limited to following up and compiling those plans.

The Keidanren is composed of companies and organizations that span many industries, and each industry has a different business form, business model, and unique circumstances. As a business association, it seems that the best they can do is to set yardsticks such as waste reduction and resource recycling that are easy to measure as achievements of the 3Rs, and it is difficult to discuss the transformation of business models in each industry.

2-4. Policy of industry association: the Japan Electronics and Information Technology Industries Association

In addition to corporate membership, the Keidanren has a membership status called group membership, and more than 100 industry associations are group members. The Japan Electronics and Information Technology Industries Association (JEITA) is one of these group members, comprising companies in the information technologies and electronics industries. In accordance with the Voluntary Action Plan for the Formation of a Recycling-Oriented Society established by the Keidanren, it has set industry-specific targets for reducing the amount of industrial waste, final disposal rate targets, and plastics-related targets.

In addition, as an industry-specific initiative to create a recycling-oriented society, it is reducing the environmental impact of products throughout their life cycles. For example, companies that deal in home appliances are working on product assessments based on the "Home Appliance Product Assessment Manual". This is a manual aiming for designs that take into account resource conservation, designs that contribute to long-term use by adopting long life parts, and designs that take recycling into consideration by selecting materials that are easy to recycle. In addition, it promotes the proper disposal and reduction of waste by taking back household equipment waste in accordance with the Home Appliance Recycling Law, and increasing the recycling rate by developing new recycling technologies to promote the effective use of recycled resources.

In addition to setting industry-specific targets for waste reduction and plastic reuse, the JEITA has created a manual on approaches to incorporating environmental impact reduction throughout the life cycle from the design stage, and is working to disseminate it to member companies. The JEITA is also promoting the search for a recycling-oriented business model that suits the characteristics of the industry. For example, in October 2021, the JEITA established the Green x Digital Consortium, which aims to create a new society and market using digital technology (JEITA, 2021). The goal of the consortium is to create and implement new digital solutions that will lead to the transformation of industry and society in order to promote carbon neutrality.

As an industry association in the field of home appliances and information technologies that is undergoing rapid model changes, the JEITA and its member companies are under pressure to change their conventional business models based on mass production and early replacement. While taking advantage of being good at digital and AI technologies, it will seek to make bold shifts of its business model, from product planning through sales methods, toward a circular economy.

3. Case Studies of Sony Corporation

3-1. Sony's environmental plan “Road to Zero”

Sony's basic policy for its efforts to achieve a circular economy is to realize a healthy and enriched sustainable society and to achieve zero environmental impact by 2050 throughout the life cycle of its business activities and products (Sony 2023a). For this purpose, it has formulated and announced the environmental plan "Road to Zero" (Sony, 2023b). Sony has set targets for its business activities and the entire life cycle of its products from four environmental perspectives, which are climate change, resources, chemical substances, and biodiversity (Fig.1).

(a) Climate change

Sony is promoting energy conservation and the introduction of renewable energy at its business sites, and manufacturing contractors and parts suppliers are also required to reduce greenhouse gas emissions. For example, with an awareness of energy conservation, it has introduced high-efficiency refrigerators, air conditioners, inverters, etc., and it is also accumulating environmental activities such as turning off the power on holidays, using LED lighting, and managing air conditioning. In addition to raising environmental awareness by visualizing the amount of electricity used, it aims to establish new environmental technologies such as environmental monitoring using IoT by combining sensing and simulation technologies. It also aims to increase the use of renewable energy-derived electricity in its operations to 100% by 2030 through the introduction of solar power panels and the purchase of renewable energy power certificates. In addition to these activities at its business sites, Sony is developing and providing environmentally friendly products and services to reduce greenhouse gas emissions.

Sony Computer Science Laboratories (CSL) is developing an open energy system (OES), a distributed energy system that can be flexibly interchanged within a community by stockpiling electricity derived from renewable energy. This technology not only smooths out fluctuations in the amount of renewable energy generated, but also motivates people in the community to change their behavior by being aware of the supply and demand of power. Since OES is operated autonomously using distributed power sources and storage batteries, it is highly resilient to natural disasters and can be introduced by businesses, municipalities, and even individuals. Sony CSL aims to promote the implementation of OES through open innovation and to further develop environmental technologies.

(b) Resources

Throughout the life cycle of its business activities and products, Sony is promoting "minimization of input resources" and "maximization of recycling." Specifically, "minimization of input resources" refers to the aim of reducing input resources such as materials and electricity as much as possible by reducing the weight of products and improving resource efficiency. Sony is also working to switch from plastics to resources that have a low environmental impact. For example, "Original Blend Material (OBM)" is an environmentally friendly paper material developed by Sony. It does not rely on petroleum-based plastics, but uses materials such as bamboo, sugarcane fiber, and market-recovered recycled paper that can be procured locally in Asia, where the Sony's largest manufacturing bases are concentrated. The entire package, including the outer box, inner box, cushions, sleeves, product protection sheets, and instruction manuals, can be composed of OBM. Sony's medium-term environmental target, Green Management 2025, aims to eliminate all plastic packaging materials for newly designed products by 2025 and replace them with OBM.

On the other hand, "maximizing recycling" is an initiative to promote the collection of used products around the world and to utilize the recycled resources in collaboration with recyclers as recycled resources for products. Various auxiliary materials used to transport parts (airbags as cushioning materials, cartons used to transport TV panels, cartons used to protect air cargo, etc.) are also reused and recycled to help reduce waste. In addition, Sony is working to reuse the water used for cleaning parts, air conditioning condensate water, rainwater, and well water, and relocating the water piping on the premises to the rooftop to make it easier to detect leaks at an early stage and make repair work easier.

(c) Chemicals

In addition to complying with laws and regulations, Sony has established its own chemical substance management standards and thoroughly manages chemical substances contained in the raw materials and parts of its products worldwide. While reducing or replacing substances with environmental impact in its own manufacturing processes, Sony is also calling for a ban on the use of substances designated by it in the manufacturing process of the supply chain. Sony has introduced the "Green Partner Environmental Quality Certification System" as a system to ensure that suppliers comply with these standards and regulations, and it procures only from suppliers that have been certified as green partners.

In addition, chemical substances used in the production process are thoroughly managed and monitored to ensure that they do not affect the environment such as rivers and soil. These measures include a rainwater final discharge monitoring and emergency shut-off system, a ground-based installation of tanks and piping, a chemical leakage prevention system, and six-sided inspections of waste liquid tanks.

(d) Biodiversity

Sony is working to conserve biodiversity so that all living things can live in balance by suppressing its impact on nature as much as possible. Sony CSL is developing a symbiotic farming method that uses AI technology to artificially create ecosystems where useful plants can grow, and enriches biodiversity while harvesting food. There are more than 30,000 kinds of useful plants on the planet that can be used as food, but current agriculture is biased toward growing specific crops. As a result, this has the effect of destroying the natural environment and damaging biodiversity on a global scale. Symbiotic farming is the process of producing food, as the number of various creatures, plants, animals, and microorganisms increases, creating a rich ecosystem. Sony is aiming to enrich the natural environment and living organisms, and to create a cycle of mutual circulation of cultural diversity and ecosystem diversity.

3-2. Initiatives throughout the life cycle

The product life cycle is divided into six stages: (a) planning and design of products/services, (b) operation, (c) procurement of raw materials and parts, (d) logistics, (e) collection and recycling, and (f) innovation (Fig. 2). Specific goals are set for achieving zero environmental impact in each stage (Sony, 2023c).

(a) Planning and design of products/services

Sony is demonstrating its creativity and technological capabilities to promote the introduction of environmentally friendly features in its products. In this way, it is trying to create products that are inspired by the environment.

(b) Operation

Targets for greenhouse gas emissions and waste are set in a unified manner across the globe, with the aim of minimizing the environmental impact of factories and offices. This is not limited to Sony's own operations; the company is also working with raw material and parts suppliers and manufacturing contractors to reduce the environmental impact of the entire value chain.

(c) Procurement of raw materials and parts

In order to reduce the environmental impact of products throughout their life cycle, it is necessary to broaden the scope of zero emission to the procurement of raw materials and parts. In addition to the management of chemical substances, Sony is also working with suppliers in terms of energy and water conservation to reduce the environmental impact to zero.

(d) Logistics

Much energy is also spent on transporting products and components. By reducing the size of packaging materials and improving loading efficiency, and switching to railways and ships with less environmental impact, Sony aims to reduce CO_2 emissions related to product transportation and reduce its environmental impact to zero.

(e) Collection & Recycling

In providing products as a company, it is necessary to be responsible for the processing of those products after the customer has finished using them. Sony is promoting the collection and recycling of used products by making the products easy to recycle and building a recycling system that meets the needs of local communities.

(f) Innovation

Building on its tradition of innovation, Sony is working to develop innovative technologies and services that are environmentally friendly and to create business models that reduce its environmental impact.

3-3 Summary of Sony’s case studies

Sony's efforts toward a circular economy have been reviewed as above and, as indicated by the name "Road to Zero," its activities that are actually being promoted are efforts to reduce the environmental impact to zero. Sony has set numerical targets for the reduction of greenhouse gases and waste generated from its factories and offices, and is implementing measures to achieve those targets worldwide. This goal takes into account reducing the environmental impact at all stages of the product lifecycle, from product design and development to procurement, production, logistics, and collection. It is also committed to addressing environmental issues across all aspects of its business activities, including requiring its suppliers and contractors to do the same. As a manufacturing company, Sony has taken all possible measures to dispose of waste and manage chemical substances. When it came up with the idea of aiming for a circular economy, the company further raised the level of its efforts and set clear targets of using 100% renewable energy in its own operations by 2030 and achieving zero environmental impact by 2050.

However, even if such an initiative raises its target, it is an extension of the 3R initiatives that have been carried out in the past. The company has not yet been able to transform its business model beyond the framework of environmental protection and create new added value through such transformation. Sony is also exploring new business models for a circular economy, such as a decentralized open energy system and a symbiotic farming method; however, all these activities are still in the development stage at the research institute and it still remains uncertain whether these new ideas will be able to blossom as businesses.

4. Conclusion

In Japan, two government agencies are responsible for policy making for a circular economy. While the MOE is responsible for protection of the environment, the METI is mainly involved in policymaking from the perspective of economic activities. The overall government's policy for the circular economy is to build corporate competitiveness and increase corporate value over the long term by shifting corporate activities to a circular model, while strengthening the 3Rs as environmental protection. In order to achieve this, the government intends to provide soft-law guidelines and milestones, but will leave it to the voluntary efforts of industry.

In response to this policy, the Keidanren has formulated a voluntary plan for the formation of a recycling-oriented society. However, since there are a wide variety of industries, each industry association individually sets specific targets, such as the amount of final disposal of industrial waste and the amount of reduction in plastic use. The Keidanren takes the position of conducting an annual follow-up survey on the progress of these targets and announcing the results.

In addition to setting its own environmental targets, the JEITA, a leading industry member of the Keidanren, has been creating manuals for design methods that incorporate environmental impact reductions, and developing new recycling technologies, and the results of these efforts are being used by Sony and other member companies. However, the transformation of business models toward a circular economy is largely dependent on management policies and business strategies, so the current situation is that it is left to the judgment of individual member companies. Many of the member companies of the JEITA are following established policies to reduce or eliminate the use of plastics and replace them with environmentally friendly materials. However, the current situation is that only a limited number of companies are shifting their business models toward a circular economy, such as providing functions instead of goods.

At Sony, this initiative is still at the development stage in the laboratory level. Sony, one of Japan's leading electronics companies, has innovated a number of products. While making use of this tradition, Sony is working to develop innovative technologies and services that are environmentally friendly, as well as to create new business models that lead to the reduction of the environmental impact. When innovations in technologies, services, and new business models improve the sustainable competitiveness of the company and lead to an increase in corporate value over the long term, the circular economy policies of Japan will see fruitful results.

Construction Sector

Towards Circular Construction: Novel Approaches in the German Construction Industry

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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. Construction engineering companies like Ed. Züblin AG has already started its endeavors in circular construction to promote a circular economy in Germany. Furthermore, 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, Germany, 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.

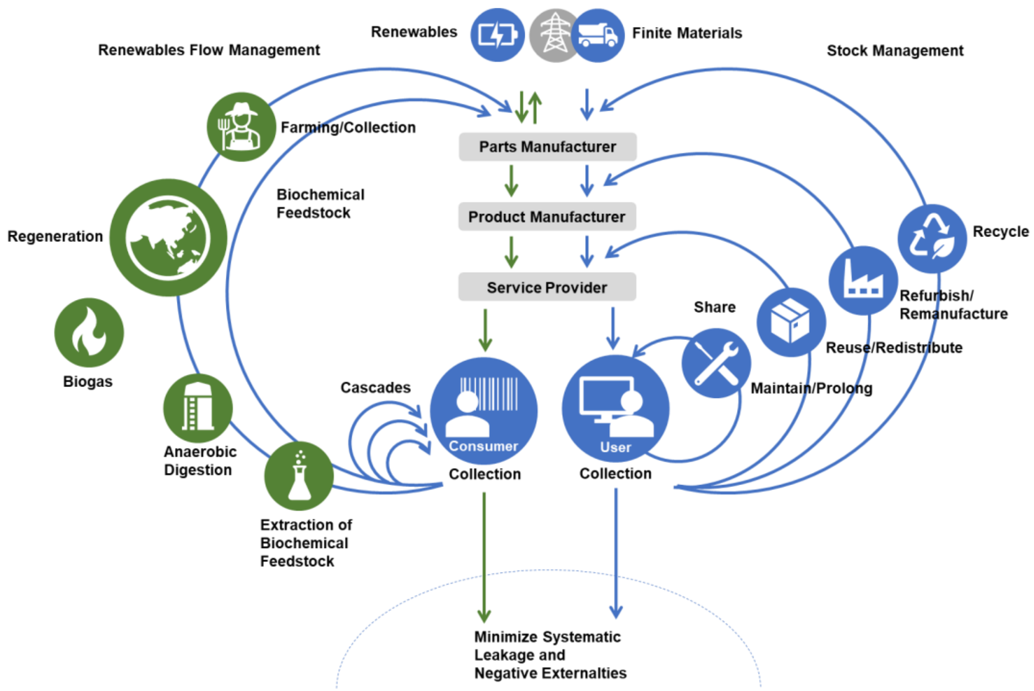

Figure 1 Circular economy systems diagram (adapted from Ellen MacArthur Foundation, 2013)

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 policies 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 policies 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. Overview of circular construction landscape and case study in Germany

Compared to many other countries, Germany tends to have medium to small sized, highly specialized, locally oriented companies ("hidden champions") in terms of design, construction, and manufacturing in the construction sector with a few exceptions. Like in many other countries, companies in the construction industry of Germany can be generally categorized into several types including design and planning firms (e.g., GMP Architekten, HENN, HPP Architekten, Auer Weber, etc.), construction contractors (e.g., Ed. Züblin AG, Max Bögl Group, Goldbeck GmbH, Hochtief AG, etc.), and construction equipment providers (e.g., Liebherr Group, Putzmeister, PERI Group, Bauer AG, etc.), see Figure 2. In recent years, many of these companies have focused their efforts on sustainable development, although not necessarily on circular construction due to its novelty.

Figure 2 Major companies in the German construction industry

One of these companies that really stands out in circular construction is Ed. Züblin AG. Ed. Züblin AG (parent: STRABAG SE) headquartered in Stuttgart, Germany. Since its founding by Swiss engineer Eduard Züblin in 1898, Ed. Züblin AG is now one of the largest building construction and civil engineering companies in Germany. Züblin has 14,000 active employees, and its annual revenue reached 4.2 billion euro, as of 2021. Sustainability is one of the guiding principles of Züblin. In recent years, Züblin started its endeavors in circular construction to promote a circular economy in Germany. In particular, the company employs a cradle-to-cradle approach, where construction products are designed to be reused or recycled at the end of their lifecycle. Its practice of circular construction is mainly reflected in the following aspects:

1) DGNB Sustainable Construction Sites (first DGNB certified company in Germany):

- Adopting green electricity: All Züblin's construction sites in Germany are supplied exclusively with green electricity from hydropower.
- Applying 5S method: The 5S method (sort, systematize, shine, standardize, self-discipline) sets clearly defined standards for order and cleanliness on all Züblin construction sites.
- Advanced energy management: The systematic and continuous application of energy management (ISO 50001:2018) creates transparency with regard to energy consumption and supports the construction site teams in reducing their CO2 emissions.
- Implementing lean Construction: With lean management methods, the construction process is precisely timed within the team, avoiding waiting time or interface problems.
- Digitalization of processes: Mobile applications facilitate documentation and verification during project management. For example, app-based digital checklists make it possible to review and document the high standards for health, safety and environmental protection during construction site inspections.

2) The company adheres to the following standards and certifications:

- Quality management DIN EN ISO 9001: 2015
- Work safety SCCP: 2011, DIN ISO 45001:2018
- Environmental protection DIN EN ISO 14001: 2015, EMAS
- Waste disposal company (EfB)
- Energy management DIN EN ISO 50001: 2018
- Value management EMB
- Level-3 carbon-conscious company by independent auditor DNV (Det Norske Veritas)

3) Alliance between Züblin and Magotteaux (parent: Sigdo Koppers):

- Züblin has entered an alliance with the Sigdo Koppers company Magotteaux.
- Since October 2022, these two companies have been working together on the recovery of scrap, recovering around 5,040 tons of steel and avoiding the emission of more than nine thousand tons of CO2 into the environment.
- With the sustainability group strategy adopted in 2021, Züblin together with its parent company Strabag will become climate neutral along the entire value chain by 2040.

4) R-concrete: Züblin's key to circular design and construction (see Figure 3)

- Recycled concrete (R-concrete, also known as resource-saving concrete) is produced with a significant proportion of recycled concrete aggregate. The production of recycled, resource-saving concrete involves the use of recycled construction aggregates, for example from concrete waste and building rubble, instead of standard raw materials such as gravel, sand and crushed rock.
- It has key features such as short transport distances for increased environmental quality, usage not only in building enclosures but also possible in load-bearing structures, and reduced construction waste thanks to recycling (instead of downcycling which is already common in the German construction sector).
- R-concrete already has been applied in several projects conducted by Züblin. For example, Factory 56, the carbon-neutral Mercedes-Benz production facility in Sindelfingen, was built by

Züblin on a turnkey basis. The façade of the building was made using R-concrete. Another example is the sustainable and resource-saving realization of the New Esslingen District Office following a customized concept for circular construction. First, Züblin systematically demolished the old building. Second, the company used the recycled building materials during the turnkey construction of the new building. The structural framework, for example, was cast to a large extent from the resource-saving R-concrete.

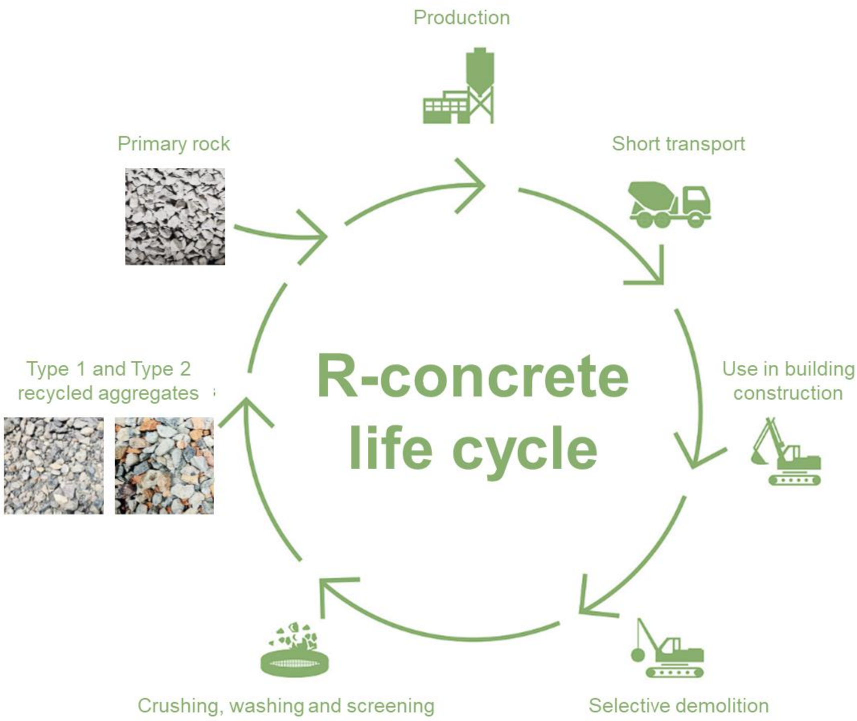

Figure 3 The life cycle of R-concrete (adapted from https://work-on-progress.strabag.com/en/materials-circularity/recycling-beton-overview)

3. A case for construction automation and robotics

Another technology that could play a crucial role in promoting circular construction in Germany and beyond is construction 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.

3.1 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 4) 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 5) 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 6) have also become a worldwide research and development topic (Bock and Linner, 2016a).

Figure 4 Stationary use of construction robots in the factory at Sekisui Heim and its legendary M1 model (photo: T. Bock)

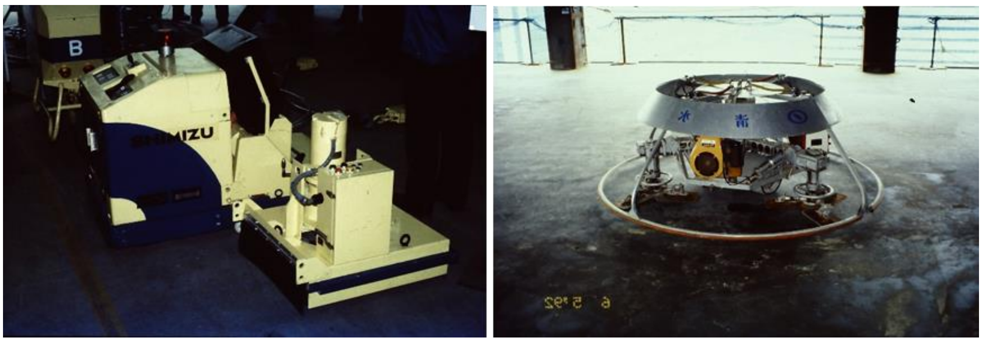

Figure 5 First on-site construction robots developed by Shimizu Corporation (photo: T. Bock)

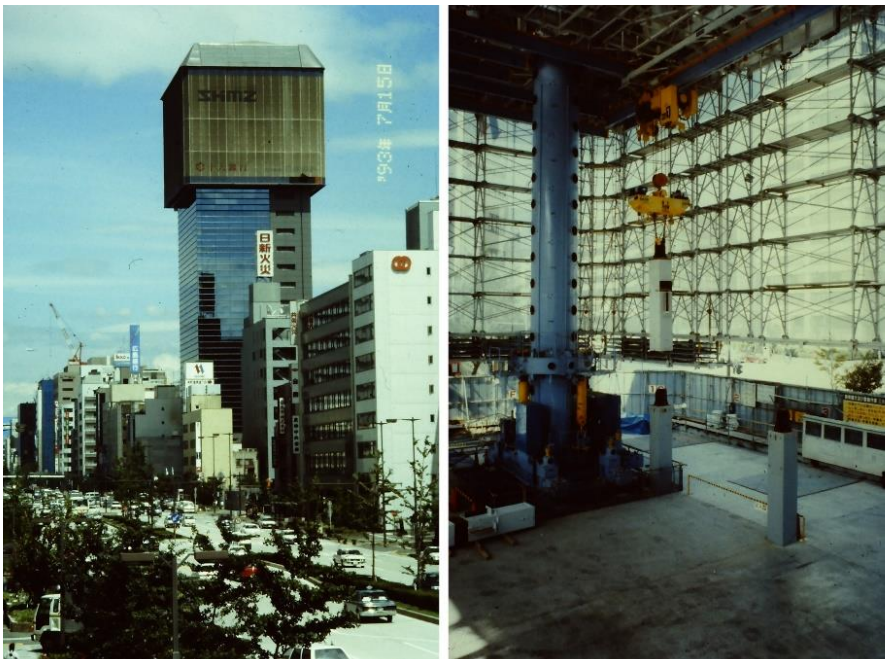

Figure 6 The pioneering automated construction site "SMART" developed by Shimizu Corporation (photo: T. Bock)

Further innovation push was triggered by earthquakes, landslides, volcano eruptions, and tsunamis where initially since 2000s, teleoperated construction robots (see Figure 7) 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 8). For maintenance, inspection, and repair of buildings and infrastructure such as tunnels, roads, dams, and power plants, various maintenance robots were developed (see Figure 9).

Figure 7 Teleoperated construction robot for tunnel construction (photo: T. Bock)

Figure 8 Autonomous heavy machinery fleet for infrastructure projects (Photo: T. Bock)

Figure 9 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 10) 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 10 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 6) 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).

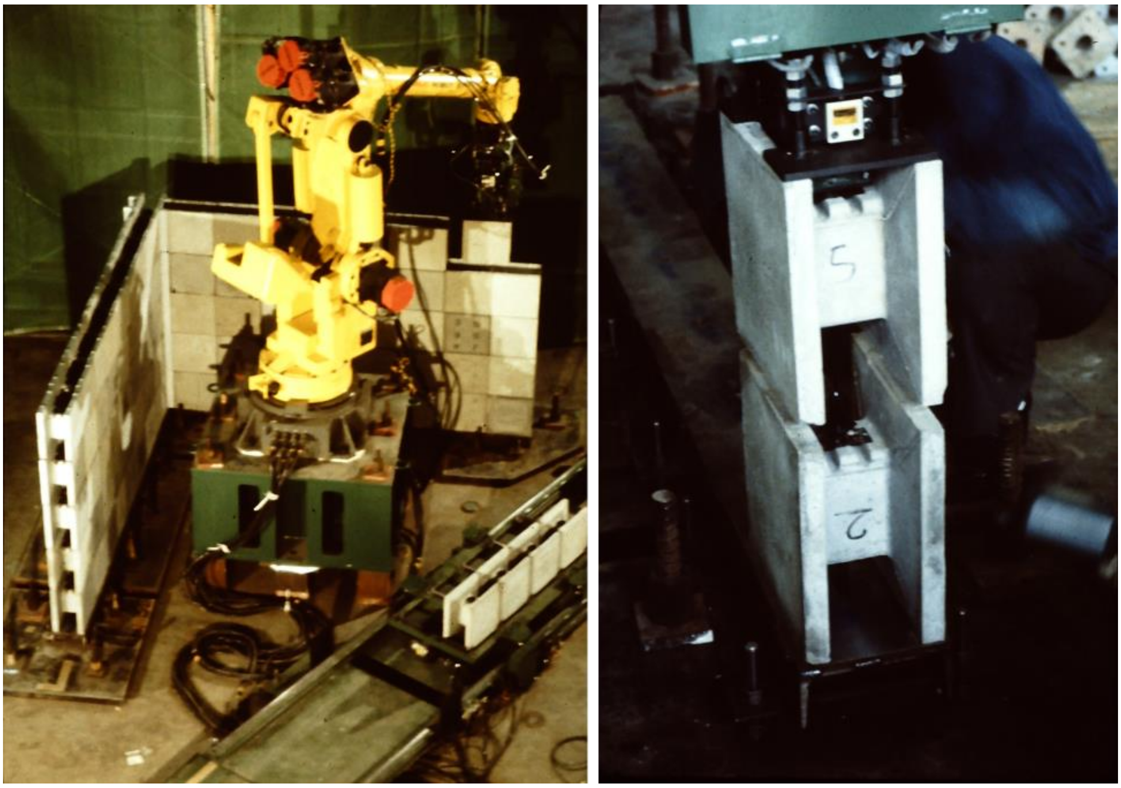

Figure 10 The SMAS robot developed for the assembly and disassembly of reinforced concrete blocks using Robot-Oriented Design concept (photo: T. Bock)

3.2 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 11) 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 12).

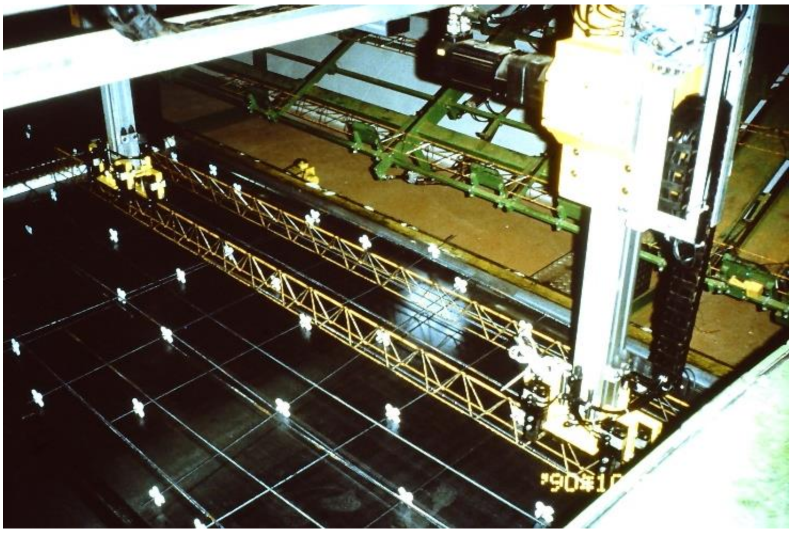

Figure 11 Robotic reinforced concrete parts production system for the “x8 Haus” (Photo: T. Bock)

Figure 12 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.

3.2.1 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 13 and Figure 14). 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 13 The multifunctional façade-processing robot showcasing the painting function on the façade of public housing buildings in Hong Kong (image: R. Hu)

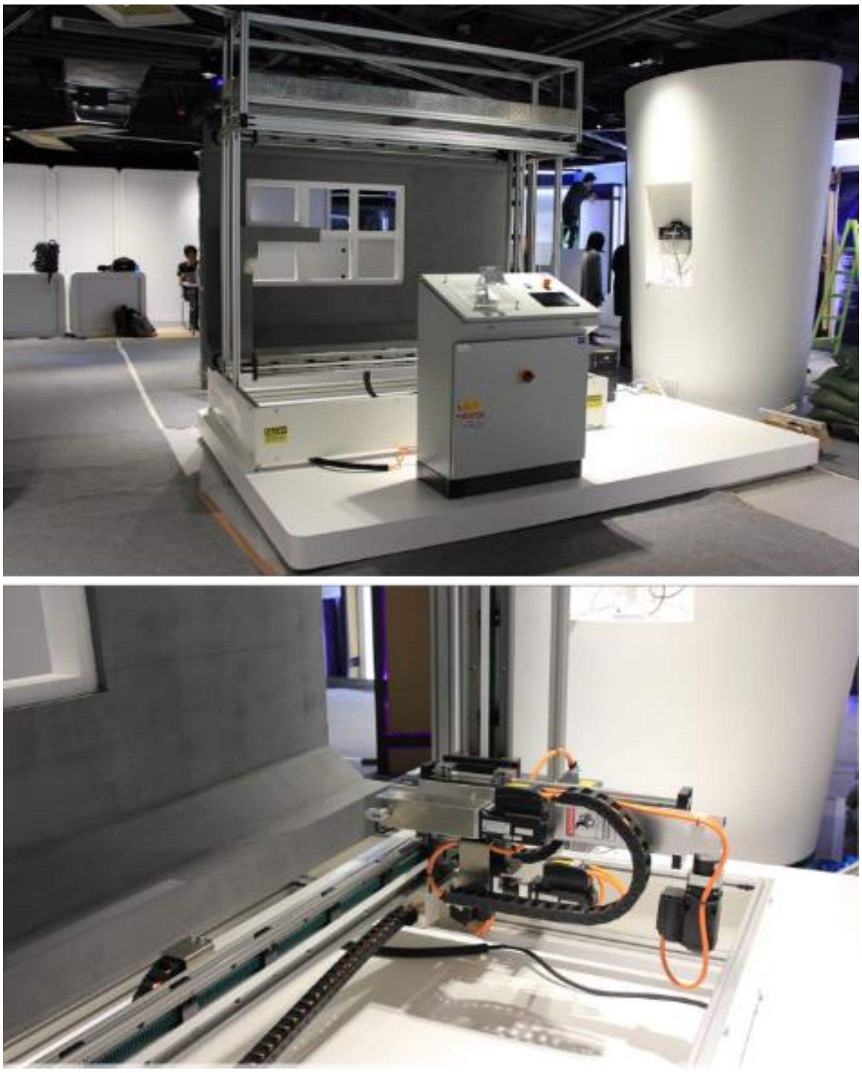

Figure 14 The semi-functional prototype of the multifunctional façade-processing robot displayed in the Construction Innovation and Technology Application Centre in Hong Kong (photo: R. Hu)

3.2.2 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 15) and a set of robotic tools named as Modular End Effector (MEE, see Figure 16). 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 15 HEPHAESTUS cable-driven façade installation robot on a testing site (photo: T. Bock)

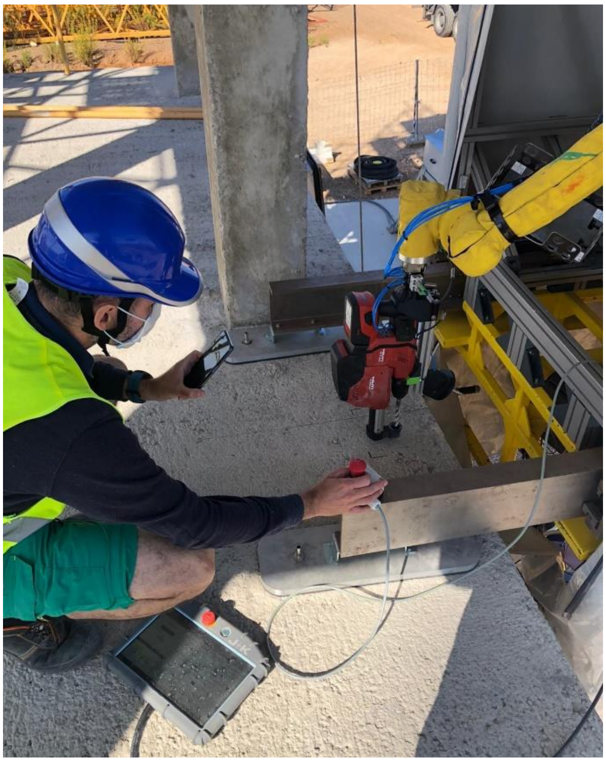

Figure 16 Checking the performance of the modular end-effector of the HEPHAESTUS robot (photo: S. Palencia Ludeña)

3.2.3 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 17) is developed for larger commercial, and industrial applications, while the "COMPACT" range (see Figure 18) 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.

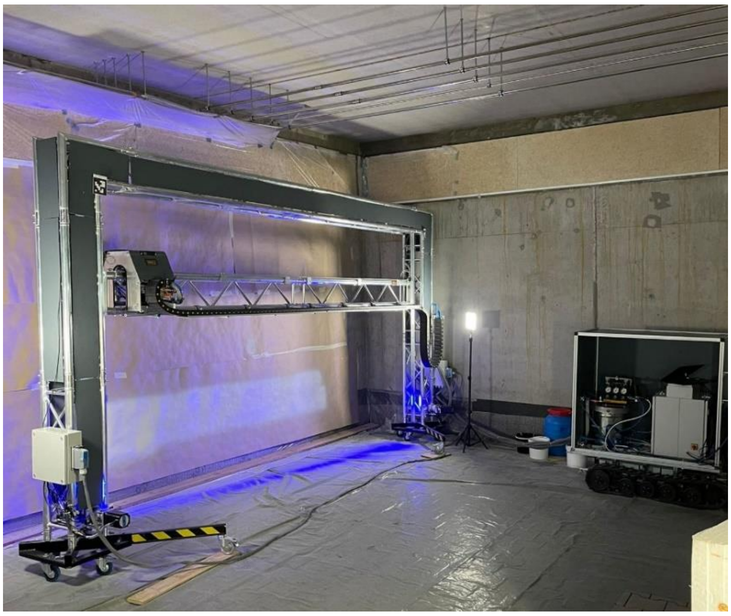

Figure 17 Prototype of the “TITAN” range on a pilot project site (photo: ARE23 GmbH)

Figure 18 Proof-of-concept prototype of the “COMPACT” range (photo: ARE23 GmbH)

3.2.4 KEWAZO hoisting robot for vertical material transport

Scaffolding assembly, a potentially hazardous and time-consuming task in construction, is responsible for the majority of casualties within the construction industry in most industrialized nations (Follini et al., 2018). Therefore, it is highly urgent to improve the safety and efficiency of the scaffolding assembly process.

Co-founded by several TUM graduates including former members of the Chair of Building Realization and Robotics in 2018, KEWAZO GmbH emerged with a clear mission to transform on-site construction operations through the implementation of robotics and data analytics. The founding team brought together diverse expertise in construction robotics, civil engineering, computer science, and business. The company revolutionizes the challenging realm of scaffolding, a profession known for its extreme complexity, laboriousness, and danger. By harnessing the power of automation and intelligence, KEWAZO's innovative approach supersedes hazardous logistical procedures, offering unparalleled efficiency to the construction industry. KEWAZO offers LIFTBOT, an intelligent robotic hoisting system for the construction and industrial sectors. One of its first application cases of the technology is scaffolding. LIFTBOT involves a state-of-the-art robotic hoist system integrated with a data analytics platform. Addressing the critical issue of labor shortages and safety in the construction especially for scaffolding, KEWAZO's innovative approach saves up to 70% of labor costs while simultaneously enhancing the working conditions and safety for the aging construction workforce. Furthermore, the robotic system boasts effortless installation, requiring under 20 minutes and minimal space. It operates wirelessly and with great degree of autonomy, granting the customers seamless control and ease of operation (see Figure 19) (KEWAZO GmbH, 2023).

Figure 19 KEWAZO's LIFTBOT in operation on a construction site (photo: KEWAZO GmbH)

Currently, the company has already more than 20 robots on-site all over the EU, UK, and US. Soon the solution will be used to transport all kind of construction materials on construction and industrial sites. It has become a global leader among construction robotics start-ups, with a dedicated team of over 40 employees and two locations in Germany and the US. In 2023, the start-up announced the closing of its $10 million Series A funding round, bringing the total funds raised to date to approximately $20 million. Through close collaboration with its customers, manufacturing partners, and industry experts, KEWAZO is marching ahead to digitalize construction sites and elevate the working conditions for millions of construction workers worldwide (KEWAZO GmbH, 2023).

4. Key learnings and potential risks of Germany's circular construction

Compared to other countries, Germany usually has small to medium sized, highly specialized, locally oriented companies ("hidden champions") in terms of design, construction, and manufacturing in the construction sector with a few exceptions.

Circular construction is a very new concept for the construction industry in Germany, but it has huge potential in addressing the critical social, environmental, and economic issues of our time. Therefore, innovative approaches need to be adopted in parallel to achieve the goal of circular construction.

As more and more construction companies begin to set foot in circular construction, however, the implementation process of circular construction should avoid the following main dysfunctions (Diaz Gonçalves & Saporiti Machado, 2023):

- Greenwashing which means that employing persuasive marketing and public relations language to deceive customers into believing that their products, services, or procedures have a significant positive impact on the environment, when it is not entirely accurate or not true at all.
- Commodification which indicates that environmental and social considerations will be esteemed and safeguarded only if they provide profits.
- "Cherry Picking" which suggests that only put emphasize on selected aspects in sustainability that are easy to achieve or profitable while ignoring other relevant but important environmental or social aspects.

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. Construction engineering companies like Ed. Züblin AG has already started its endeavors in circular construction to promote a circular economy in Germany.

Furthermore, 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 20) and constructing space architecture (Figure 21).

Figure 20 Concrete dismantling and recycling robot Garapagos (Photo: T. Bock)

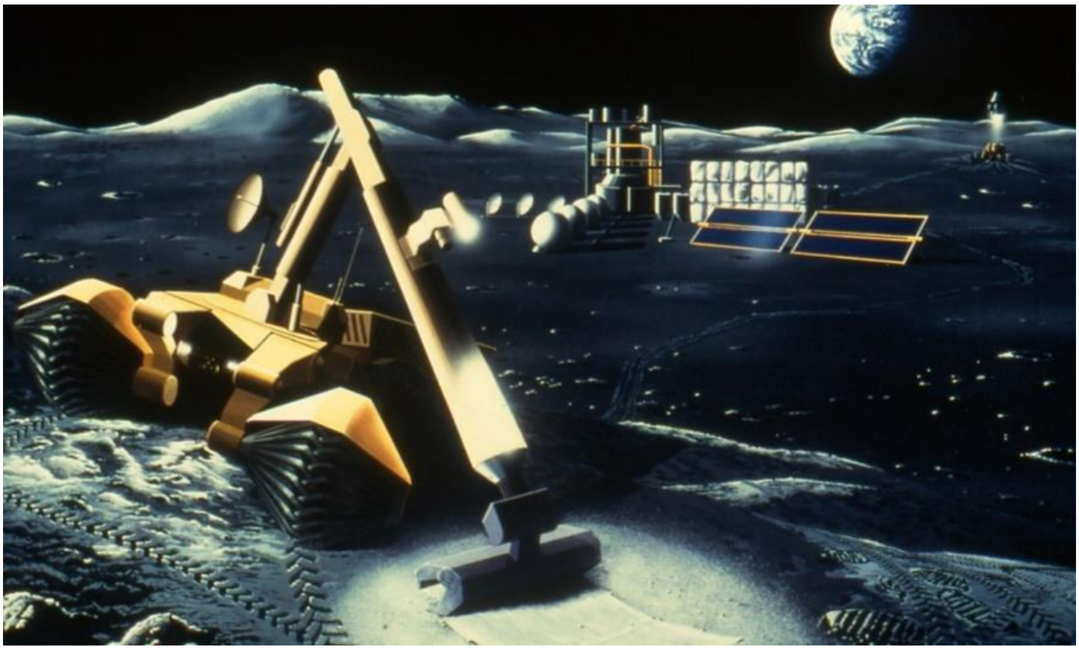

Figure 21 Next frontier for construction robotics: space stations and colonies (Photo: T. Bock)

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Applying Circular Economy in the Construction Sector: a Case-Study Analysis from Italy

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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 International, European and Italian level, starting from ISO standards which are currently under development, the first circular economy action plan enacted in 2015, 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 thar has been updated in 2023. 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 an overview of the circular economy application in the Italian construction sector, and the Webuild company case study is presented.

Keywords: Circular economy, Construction sector, Italy.

1. 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 has 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 (CO2) that accounts for about two-thirds of GHGs. It is largely the product of burning fossil fuels.

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 produced (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, 2023) 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 it has been demonstrated the validity of the concept, 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).

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

2. Circular economy policies at international and European level

2.1 The international level

The technical Secretariat ISO/TC 323 has been established in 2018 made up of experts from over 65 different countries and growing, with the aim to develop International standards related to CE to establish a common reference and standardize the implementation of CE principles in organizations and business models. The ISO 59000 series of documents that are still under development, even though four out of six are in a more advanced status, being the final text received or registered for formal approval (DIS or FDIS). The other two are still in their infancy, being or with a committed draft received (CD) or with proof sent to secretariat or ballot initiated (DTR). More details are provided below.

1) ISO/FDIS 59004 - Circular Economy – Terminology, Principles and Guidance for Implementation https://www.iso.org/standard/80648.html?browse=tc

This document defines key terminology, establishes circular economy principles, and provides guidance for its implementation by using a framework and areas of action. It is intended for private or public organizations, acting individually or collectively, regardless of their type or size, and located in any jurisdiction or position within a specific value chain or value network.

2) ISO/FDIS 59010 - Circular Economy — Guidance on the transition of business models and value networks https://www.iso.org/standard/80649.html

This document provides guidance for an organization seeking to transition its business models and value networks from linear to circular. This document applies to any organization dealing with products or services regardless of its size, sector or region.

3) ISO/FDIS 59020 - Circular Economy — Circular Economy — Measuring and assessing circularity https://www.iso.org/standard/80650.html?browse=tc

This document specifies a framework for organizations to measure and assess circularity, enabling those organizations to contribute to sustainable development. It is applicable to multiple levels of an economic system, ranging from regional, inter-organizational, organizational to the product level. The framework aims at providing guidance on how the circularity performance of an economic system can be 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 framework can include consideration of social, environmental and economic impacts when assessing circularity performance by allowing input from a variety of complementary methods.

4) ISO/DIS 59040 - Circular economy – Product Circularity Data Sheet https://www.iso.org/standard/82339.html?browse=tc

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. 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 for the definition and sharing of a Product

Circularity Data Sheet, considering 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 for business-to-business data exchange to be inclusive with small and medium businesses/enterprises and to protect confidential information.

5) ISO/CD TR 59031 - Circular economy – Performance-based approach – Analysis of cases studies https://www.iso.org/standard/81183.html?browse=tc

Not updated information are available since it is still at the beginning of the process.

6) ISO/DTR 59032- Circular economy – Review of business model implementation https://www.iso.org/standard/83044.html?browse=tc

Not updated information are available since it is still at the beginning of the process.

The relation between the standards can be exemplified as follows:

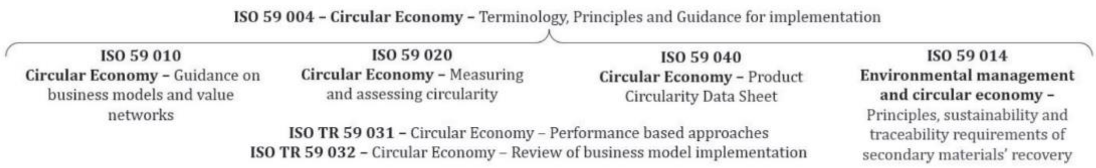

Figure 1: relation between the CE ISO standards. Source: draft of ISO standards available at https://www.iso.org/obp/ui/en/#iso:std:iso:59020:dis:ed-1:v1:en

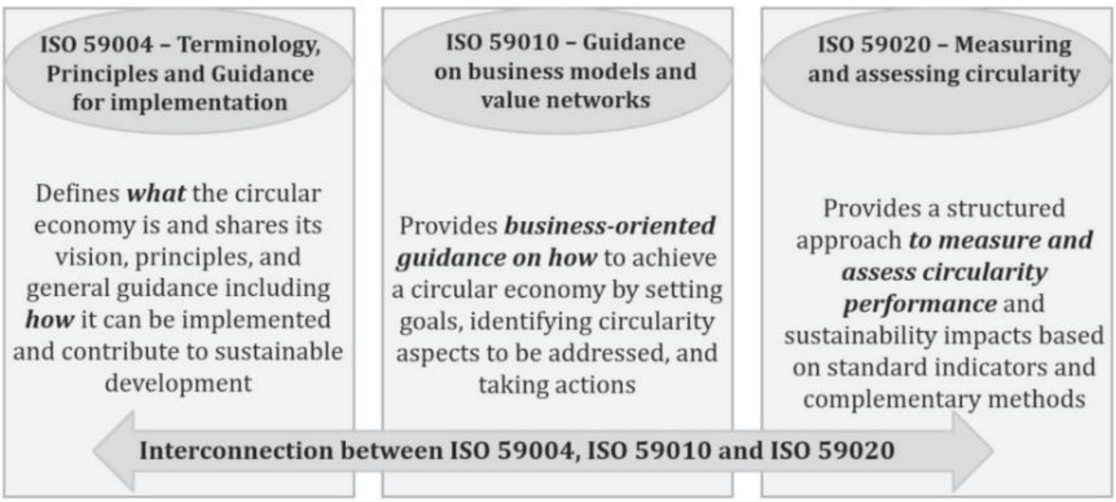

Figure 2: relation between the CE ISO standards. Source: draft of ISO standards available at https://www.iso.org/obp/ui/en/#iso:std:iso:59020:dis:ed-1:v1:en

In particular, for the ISO 59004 standard a preview of the contents is available. The document is about CE principles and guidance for implementation, proposing a sequence of steps for CE implementation in organizations, summarized below.

- **Analysis of the context and reference situation when it comes to the CE**, through the analysis of current resource management, the flow of resources, sectors with relevant opportunities in terms of circularity transitions, the analysis of the current environmental impact as well as social implications, exploration of options to use energy and sustainable resources, assessment of legal and regulatory requirements that could influence the action plan. In addition, the organization should understand how much CE will be relevant for the organization and the stakeholders;
- **CE purpose, mission, vision and goals definition**. The organization is called to develop a mission in alignment with CE principles, a vision that includes a commitment and inspires actions for the transition, to be shared with local stakeholders;
- **CE strategic priorities and action plan development:** the organization should develop ideas and a list of actions, starting from those having the biggest potential that have to be prioritized. The phase is also dealing with the establishment of a monitoring strategy and the creation of value. In this case, some elements to be considered are suggested: technically and economically feasibility of CE practices that add value to the organization, a clear definition of a comprehensive CE value creation model that includes and is supported by transition pathways and, lastly, a comprehensive CE value creation model that can be achieves through implementation of relevant CE practices.
- **CE implementation.** In this phase strategic priorities of the action plan are put in place, and it is important to integrate those practices into organizational culture, through raising awareness initiatives and by building capacity.

2.2 The European level

As far as CE in Europe is concerned, the reference policy document is the **New CE 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 CE action plan was adopted. This initial plan included measures stimulating the Europe's transition towards a CE 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 CE 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 CE 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 **CE package in January 2018**. As part of this package, the development of a new monitoring system for the CE 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 monitoring framework has been updated by the European Commission in 2023, with the addition of indicators about material footprint and resource productivity in order to monitor material efficiency, and also consumption footprint to monitor if EU consumption fits within planetary boundaries. The new framework supports the EU's CE and climate neutrality ambitions under the European Green Deal.

The complete list is reported in Table 1.

Table 1 Proposed indicators for CE monitoring in EU

Category	Indicators	Notes
Production and consumption	1) Material Consumption	Production aspects (material footprint, resource productivity, green public procurement);
	2) Waste generation	Consumption aspects per municipality and per capita;
Waste management	3) Overall recycling rates	Share of recycled waste at municipal level
	4) Recycling rate for specific waste streams	Packaging, plastic WEEE.
Secondary raw materials	5) Contribution of recycled materials to raw materials demand	
	6) Trade in recyclable raw materials between the EU Member States and with the rest of the world	
Competitiveness and innovation	7) Private investments, jobs and gross value added related to CE sectors;	
	8) Innovation	Patents related to waste management and recycling
Global sustainability and resilience	9) Global sustainability from CE	Consumption footprint and GHGs emission from production activities;
	10) Resilience from CE	Material import dependency, EU self sufficiency for raw materials

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.

As part of the CE package, a Europe-wide strategy for plastics in the CE and a report on critical raw materials and the CE 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 CE action plan the consumption practices and the investments in innovation are also present. Concerning the first one, EU states that the transition towards a CE 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 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 CE policy-making globally, and the action plan encouraged at least 14 Member States, 8 regions and 11 cities to put forward CE 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 CE 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

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

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 CE Action Plan**[3]. The Commission announced that the transition to a CE 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 CE 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 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 CE action plan, many results have been achieved. The Commission adopted a proposal for a new regulation on sustainable batteries (2020), a Global Alliance on CE 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 CE action plan consisting in sustainable

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

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

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. In April 2022 both the Industrial Emissions Directive and the European Pollutant Release and Transfer Register have been revised. As far as the construction products regulation is concerned, 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. More recently, in 2023 the European Commission proposed a Directive on Green Claims and common rules for promoting the repair of goods and, as mentioned, the revision of the monitoring framework. Lastly, several initiatives have been adopted about microplastics such as the REACH restriction addressing intentionally added microplastics, a proposal for a regulation on preventing pellet losses to reduce microplastics pollution.

2.2.1 From policies to regulations in the construction sector

As previously explained, the European framework concerning the CE is of strategic nature and it is mainly represented by the CE Action Plan.

Dealing with the construction sector, the "Level(s)[5] – 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**[6], explaining the sustainability concept, how to implement it and how to measure the results. Level(s) is focusing on six overarching macro-objectives; for each of them key indicators are identified as it is show in the table below.

[5] https://environment.ec.europa.eu/topics/circular-economy/levels_en
[6] Free download available https://susproc.jrc.ec.europa.eu/product-bureau/product-groups/412/documents

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	kWh/m^2/yr
	1.2 Life cycle Global Warming Potential	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, CO2 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	€/m2/yr
	6.2 Value creation and risk exposure	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.

Specifically, potential linkages between other existing policies and regulations have been identified to integrate CE into binding requirements for Member States (European Union, 2021). Four policies are selected as potentially implementing CE principles for building design:

- Potential revision of the **Construction Products Regulation**
- Potential revision of the **Energy Performance of Buildings Directive**
- Potential revision and expansion of **GPP criteria**
- Development of **guidance for local and regional authorities**

In terms of integrating circularity into harmonized technical specifications of the Construction Product Regulations for methods and criteria to assess and declare the performance of construction products, the following actions could be useful: i)Map the various commitments, regulations, actions, initiatives, tools, standards, procurement criteria and voluntary agreements that require product level data linked to circularity to be effectively implemented. Involve the various stakeholders and policy makers in defining 'core/mandatory' and 'additional/aspirational' data fields that should be filled by construction product & material suppliers in a harmonised way; ii)Build consensus on the required data and information: Define the 'core' & 'aspirational' data and information (fields/attributes) that should be available for all construction products and materials to support circular design and implementation. This should build upon and align, where appropriate, with the harmonisation work of CEN/TC 350 –EN15804 in particular to avoid duplication of effort. It should also consider aspects of digitisation and ease of collation and updating throughout the asset/building life cycle. Define implementation mechanisms: Develop further the optimal mechanisms for reporting, transferring and updating such information by suppliers to their customers and tools that support more informed decision making, such as BIM alignment and whole life data access and updating. iii)Define implementation mechanisms for reporting, transferring and updating such information by suppliers to their customers and tools that support more informed decision making, such as BIM uploads to provide instant LCA.

In terms of integrating circularity into the revision of Energy Performance of Buildings Directive, specific aspects could embed the whole life-cycle carbon approach and circularity performance requirements for new and existing buildings. In details, EPBD could require the circularity assessment of buildings through the adoption of a general common framework into the calculation of the energy performance, such as the potential for reuse and higher values of recycling and GHGs emissions produced over the whole life-cycle. Also, there might be opportunities to set more ambitious targets for emissions and the use of energy in buildings. Financial measures that are linked to energy efficiency, could also be targeted towards interventions that foster circularity. Lastly, the directive imposes that owners and tenants have to be informed about the purpose, objectives and potential financial instruments available to increase cost-effectiveness, but there might be potential to incorporate guidance on the importance of CE principles for buildings design.

As for the development of revision for Green Public Procurement, it is currently a voluntary tool based on the Level(s) framework. Additional GPP requirements could be considered to further support circularity such as the development of criteria for building sectors that have not yet been covered by Level(s). 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 CE 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.

As for the provisions of guidance on local and regional planning, it has as objective the integration of circularity principles through EU funding policies. In terms of tools, the setting of circularity requirements could be within the new Cohesion funds and the renovation wave fundings. Guidance should be offered to policy makers, and should be process oriented, providing a flexible framework to them tailored to the local contexts. It could also be a guidance on how to implement Level(s).

3. CE policies in Italy

Italy is one of the EU Country having a national strategy for the CE transition. Being a Member State of the European Union, all the European Directives have been ratified in order to put in place binding targets for specific sectors. As an example, waste and energy management are regulated by specific directives at European level, and therefore targets have been transposed into the Italian legislation. Consequently, in 2002 the law no. 120/2002 put into force the target of 6.5% of reduction of GHGs emissions in the timeframe 2008-2012, as well as its update after the Doha Amendment (Law no. 79/2016) that has been valid for the timeframe 2013-2020. In 1994, Italy also ratified the UN Convention on Climate Change and in 2015 the Law no. 221/2015 has been adopted to foster green economy interventions and contain the over-exploitation of natural resources. Nevertheless, the most important policy document at national level, is the National Strategy for Sustainable Development (SNSvS), adopted in 2017 by the Italian Ministry of Environment (actually named Ministry of Environment and Energy Safety). The purpose of this document is to translate into the Italian context the principles of Agenda 2030 for sustainable development that is the basis for a global development respectful of the planet and the environment. Also in this case, a two-fold analysis is performed: if the document is directly addressing CE, the role of urban areas has been investigated, while if the document is important for sustainable development, it has been explored if the CE role is acknowledged.

3.1 National Italian Strategy for Sustainable Development (SNSvS),

Descending from the UN 17 SDGs, the SNSvS outlines the pathway to achieve the Agenda 2030 goals, tailoring them to the Italian context and targeting a sustainable future in economic, social and environmental terms, as a shared and essential value for facing the global challenges of Italy. The strategy is outlining the Agenda 2030 "5P" framework, namely People, Planet, Prosperity, Peace and Partnership, from which 15 strategies are defined covering different sectors like, among others, the management of natural resources. Additionally, 55 indicators have been identified to monitor the efforts and the efficacy of the strategies. In the preface it is stated that the document summarizes a vision for a new CE model with low CO2 emissions, resilient to climate change and other global challenges like biodiversity loss, the modification of fundamental bio-geo-chemical cycles (carbon, nitrogen, phosphorus) and changes in land use. The Italian Legislative Decree (D.lgs.) 152/2006 foresees that the strategy should be revised every three years, and therefore in 2022 an update of the SNSvS has been released. The process ended with the formulation of the new National Strategy for the Sustainable Development 2022 (SNSvS22). It worth to be mentioned that the cornerstone of the strategy is the achievement of the goals through territorialisation. In fact, within 12 months from the approval of the law, the Italian Regions and Autonomous Provinces must approve their Sustainable Development Strategy, as well as the activation of an integrated monitoring system that shows the contribution to the achievement of sustainability objectives. The Minister has always supported the decisive role that territories might have as places where the effective transition takes place. Therefore, many activities have been put in place to allow local and regional government to adopt their own instruments to both achieve the objectives established at national level and to enhance the efficacy of the monitoring system. The SNSvS22 is articulated into two parts: the first one is dedicated to the presentation of the "Vectors of Sustainability" interpreted as cross-cutting themes that intercept the aspects of interconnection and indivisibility of sustainable development objectives and are configured as enabling factors, essential to activate the transformative paths within administrations, territories and society. The second part is aimed at exploring the "5P" framework and how the SDGs have been tailored into the Italian context together with indicators and their actual values. Three are the vectors of sustainability:

1) Coherence of policies for sustainable development through a multi-governance vision, the sustainability assessment of public policies and the integrated monitoring system of sustainability assessment;
2) The culture for sustainability promoting education and training, as well as information and communication activities;
3) Participation for a sustainable development with the mapping of potential stakeholders and the institution of strategic collaboration and agreements.

When it comes to the monitoring system, the SNSvS22 has identified a core selection of 55 indicators to monitor the Italian context in relation to the SDGs and a second-level set of 190 indicators to monitor the national strategic objectives. The core selection is comprising 33 of the 43 identified indicators in the first version of the strategy, but the remaining 10 have been included into the second-level indicators.

In terms of inclusion of the CE into the strategy, an explicit link is made in the document with the National Strategy for the CE (SNEC – see the paragraph below for more details), and in the section dedicated to "Prosperity" the document is directly mentioning the necessity of creating a new circular economic model aiming at a more sustainable and efficient use of resources, minimizing the negative impacts on the environment, thus fostering the progress of human kind. In this respect, the circular material use is calculated among the core indicators, intended as the percentage of secondary raw material used into production processes as well as the recycle rate. Also, the section related to the "Planet" is proposing strategies and principles coherent with the CE ones, such as the preservation of the biodiversity, of the environment especially integrating the value of the natural capital into policies, planning instruments and monitoring tools. In addition, strategies are put in place to decrease emissions and increase the efficiency of water management systems.

However, in the Regional strategies of sustainable development annexed to the document, the CE is mentioned only when it comes to the waste management, thus confirming the sectorial (and limited) application currently adopted of the concept. The Emilia-Romagna region has inserted in the regional strategy Agenda 2030 an indicator about resource decoupling, that can be translated into the ratio between the GDP and the raw material consumption. In detail, the proposed indicators is analysing the ratio between the expenditures and incomes of the families and the production of solid waste. The Liguria region is posing the CE as a cornerstone of its strategy, promoting transversal and cross-cutting themes between CE and sectorial analysis of sustainable development. The Veneto region is adopting CE practices into the strategy of regeneration of natural capital, pursuing the circularity into production and consumption processes.

3.2 National Recovery and Resilience Plan (Piano Nazionale di Ripresa e Resilienza - PNRR)

After the Covid-19 pandemic, the EU put in place structural measures to sustain the economy of Member States by adopting the Next Generation EU (NGEU) programme in July 2020. Around €800 billion (in grants and loans) are made available to recover and to increase the resilience from the current crisis. The most relevant part is comprised into the RRF (Resilience and Recovery Facility) that has a validity of 6 years, from 2021 until 2026. To receive funds from RRF, Member States need to submit Recovery and Resilience Plans (PNRR in Italy), outlining how to invest the funds to meet climate and digital goals. Minimum 37% of the expenditures is for climate investments, while a minimum of 20% is to sustain the digital transition. The RRF is performance-based and therefore the Commission is financing each Country only when the agreed milestones and targets have been achieved. 6 policy pillars have been identified within the RRF regulation:

1) Green transition – directly linked with the EU Green Deal and the target of GHGs emissions reduction of 55% by 2030 compared to 1990's level;
2) Digital transition – monitored by the DESI index counting the digitalisation of economy and society;
3) Smart, sustainable and inclusive growth;
4) Social and territorial cohesion;
5) Health, economic, social and institutional resilience;
6) Policies for the next generation.

CE is directly mentioned in the plan, under the Green Transition pillar, even though it is targeting waste management policies such as waste prevention and recycling, prevention of pollution and control (e.g. air, water, noise, pollution) and other climate change mitigation measures such as sustainable industries.

The Italian PNRR is contributing to the six pillars as shown in the following Figure 2.

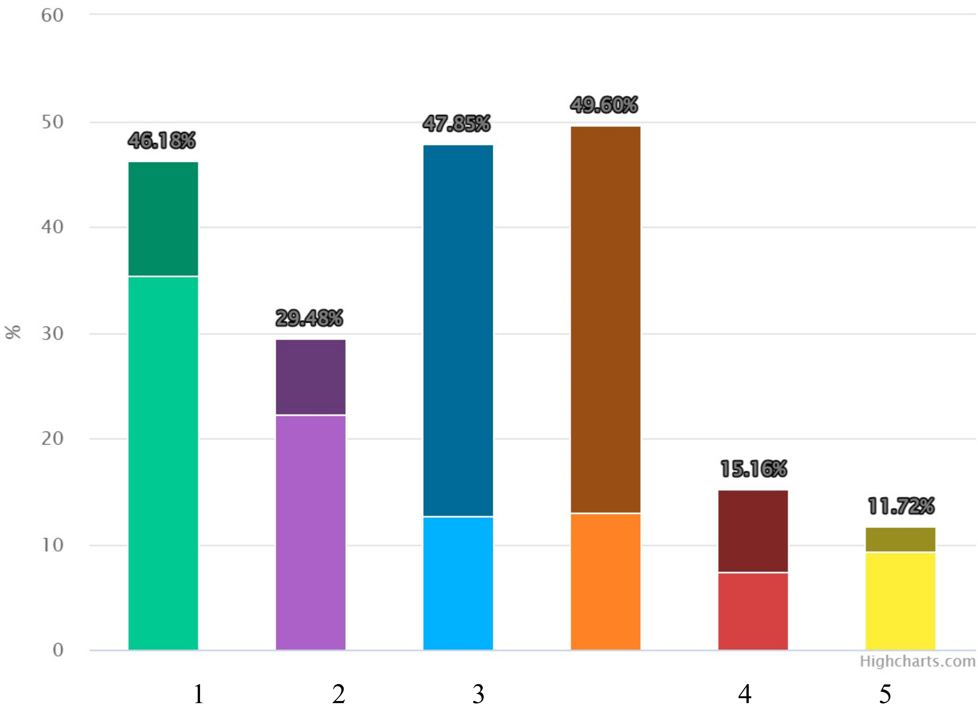

Figure 2: Contribution of the interventions to each policy pillar. Since each measure contributes to two policy areas, the total contribution is the 200% of RRF funds allocated to Italy. (Source: European Commission website)

The plan is composed by three leading strategic axis and six missions. The former are digitalisation and innovation, ecological transition, and social inclusion while the missions identified consist in:

1) Digitalisation, innovation, competitiveness, culture and tourism;
2) Green revolution and ecological transition;
3) Infrastructure for a sustainable mobility;
4) Education and research;
5) Cohesion and inclusion;
6) Health.

Mission 2 is the one more linked with CE, that is directly cited within the PNRR, even though it reflects the nature of the European RRF and mainly targets waste management and resource productivity. However, in the mission 1 component 3 dedicated to tourism and culture, CE is considered as the right perspective to promote a green approach to reduce the ecological footprint for the production and the participation to cultural events, orienting people towards more responsible and environmental-friendly behaviours. Among the mission 2 component 1 collecting measures for sustainable agriculture and CE, the National Strategy for the CE is proposed. More details are provided in the dedicated paragraph. The plan is also sustaining innovative start-ups (mission 2 component 2.5) in the CE discourse as well as the decontamination of sites left vacant by industrial activities in order to reuse them (Mission 2, component 4.3).

3.3 CE national strategy (SNEC)

As already mentioned, within the mission 2 component 1 – Sustainable agriculture and CE - the PNRR is foreseeing the adoption of a National Strategy for the CE (SNEC). Its root can be traced since 2017 when, after public consultation, the document “Towards a CE model in Italy. Document of framework and strategic positioning” has been published. The document was aiming at providing an overview of CE and the Italian positioning on the topic, ensuring coherence with the goals of Paris Agreement, the SDGs and the European Union target. After 2017, many changes in the international context occurred, like the urgency of reducing GHGs emissions, climate change strong effects, the fast technological development, the Covid-19 pandemic and Ukrainian war, to cite some of them. In addition, the new CE action plan has been issued at European level, thus influencing and supporting the transition towards circularity. Consequently, the strategic lines identified in 2017 were not reflecting the current global challenges and needed to be updated. For these reasons, the SNEC is aiming at answering the big challenges of preventing the production of waste, maximizing its recovery, reuse and recycling. Through the eco-design, durable and repairable products should be incentivized, additionally creating a new supply chain of secondary raw materials. In addition, important is the role of the Public Administration supporting the transition with a simplification of the legislation, as well as the role of citizens in terms of increased awareness and participation. A CE strategy should foster the transition towards national supply chains of energy and raw materials. Among the objectives, the strategy is identifying new administrative tools to strengthen the market of secondary raw materials making them competitive if compared to virgin raw materials (e.g. through public procurement and Minimum Environmental Criteria, end of waste, extended producer responsibility, fostering the product ad a service and sharing practices). The strategy is also aiming at identifying tools and measurable targets to achieve climate neutrality objectives.

The National Strategy for the Circular Economy proposes 5 business models capable of leading to a production system consistent with the aims of the circular economy:

1. Circular supply chain "from the beginning" (**eco-design** from the early stages of product design);
2. **Recovery** and **recycling** (manufacturing secondary raw material and other "near zero waste" strategies);
3. Extension of product life (fostering the **durability** of the product).
4. **Sharing platform** (use what you need and when you need it, creating market places in which the owners can make available their goods to whom is interested in using them);
5. **Product as a service** (which is inextricably linked to the durability of the goods above).

In Figure 4 the infographic proposed by MITE regarding the product cycle according to the circular economy is reported. Moreover, in the paragraph 9.2 of the SNEC a set of indicators is proposed to monitor each system according to the pillars for the CE, as considered in this strategy:

- Production and Consumption;
- Waste management;
- Secondary raw materials;
- Competitiveness and innovation;
- Global sustainability and resilience.

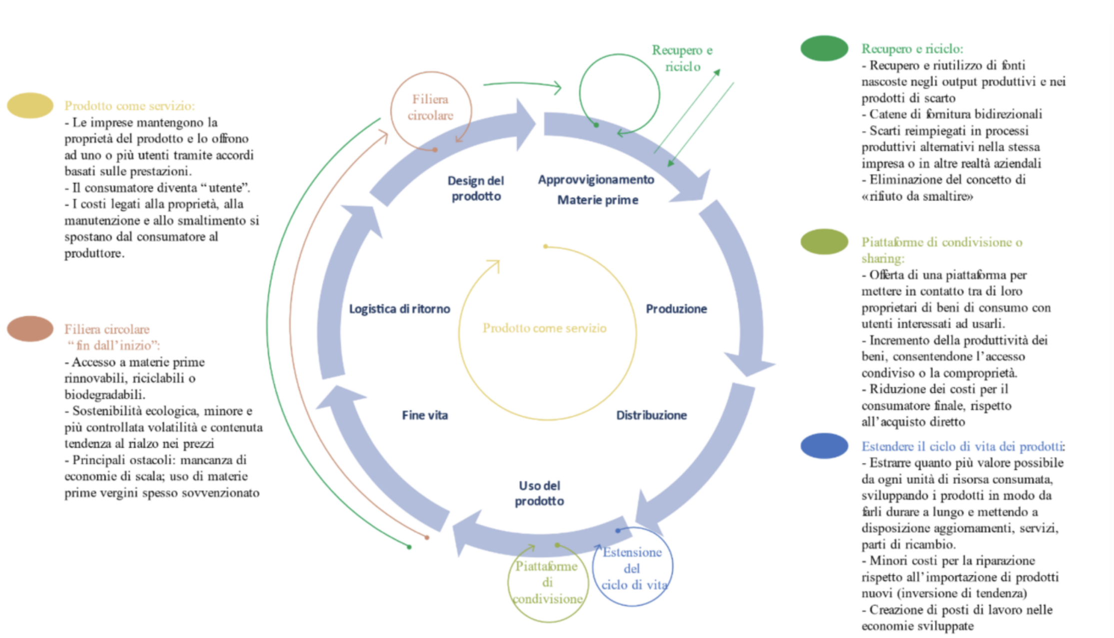

Figure 4: product cycle according to the circular economy Source: (MiTE)

In operational terms, the eco-design has been translated into a useful product development checklist, according to Menapace (Menapace, 2022):

• **Materials**: rationalize the use of material resources (efficiency in the use of materials), seeking to replace non-renewable materials with renewable, recycled, biodegradable and compostable materials. The objective is to "create" new materials that best contemplate sustainability and circularity (e.g.: secondary raw material that replaces, even partially, virgin raw material). Knowledge of the environmental characteristics of materials is essential to avoid pursuing design choices that do not favor the circularity of resources;

• **Production processes**: increasing efficiency in the use of raw materials; improve procurement and distribution logistics; minimize the production of processing waste or ensure that these are managed as by-products. Industrial symbiosis processes (where the waste of one production process becomes a secondary raw material for another) offer an important contribution to enhancing the waste of production processes by reducing process costs and obtaining revenues from sales; in order to facilitate the implementation of these processes, Decision Support Systems will have to be developed, which guarantee up-to-date and reliable data, integrating all information sources into a single access interface;

• **Procurement**: use energy supplies from renewable sources; enhance the use of resources at local level to reduce the environmental impacts of transport and create a local product identity;

• **Disassembly and modularity**: to allow the disassembly of the different components of a product more easily in relation to the types of materials used; encourage the design of products following the principle of modularity to allow the replacement of parts, the recovery and reuse of assemblies and subassemblies;

• **Recyclability**: encourage the recovery and recycling of materials, avoiding having multi-material components with irreversible joints that cannot be sent to the recycling process;

• **Repairability and maintenance**: to allow the replacement of technologically obsolete or damaged parts and to promote maintenance that allows the extension of the life cycle of the product itself;

• **Substitution and management of hazardous substances**: looking for material solutions that do not contain hazardous substances to make products more easily recyclable. However, for many products, the presence of specific hazardous substances in them is dictated by the need to guarantee certain performance and characteristics (including durability) which, on the basis of current knowledge and available technologies, cannot be achieved with alternative substances. It is therefore also necessary to ensure the proper management and recovery of hazardous substances;

• **Reuse**: any operation by which products or components that are not waste are reused for the same purpose for which they were designed;

• **Post-consumer collection**: a fundamental phase to allow a product or part of it to be sent for maintenance or reuse;

• **Regeneration**: allowing working and reusable parts of a used product to be reused in a new product/process;

• **Quality of recycling**: promoting the recycling process, trying to maintain the characteristics of the materials as much as possible. A reduction in the quality of the material inevitably leads to a lower economic value;

• **Eco-design of production processes**: from end of pipe to cleantech. "End of pipe" or end-of-cycle technologies owe their definition to the fact that they intervene on the treatment of pollution after it has been produced, thus acting downstream of the production process: gaseous emission abatement plants and biological or chemical-physical wastewater treatment plants are an example. Cleantech technologies need to intervene upstream to avoid environmental externalities, such as reducing water

3.4 Bellagio Chart (2020) and Italian Report on CE (2022)

The Bellagio declaration is a document elaborated by ISPRA[7] (Istituto Superiore per la Protezione e la Ricerca Ambientale) from Italy, European Environmental Agency (EEA) and an advisory board encompassing Environmental Protection Agency (EPA) representatives from Finland, Ireland, Netherlands, Portugal and Slovakia. Other European Institutions have been consulted to ensure the alignment with the work carried on in the European Green Deal and the CE Action Plan in order to make a step forward the implementation of the measures included therein. The Bellagio Principles is a set of seven principles that underline the essential elements of the transition to a CE:

- *Monitor the CE Transition*

The transition to a CE has to be considered holistically and among all the relevant initiatives coming from both public and private entities. The monitoring framework should assess the big picture

[7] https://www.isprambiente.gov.it/it

of the transition capturing all the changes happening to the material and waste flows, the lifecycle of products, business models and consumer behaviour, including the economic, environmental and social dimension of these changes.

- *Define indicator groups*

In this section has been outlined the topic to be considered in order to build a robust monitoring framework. Indicators should be identified for materials and waste flows, for environmental footprint assessment to respect the planetary boundaries, for economic and social impact to capture positive as well as negative impact of the transition and lastly to identify indicators that are able to reflect policy, process, and behaviour changes.

- *Follow indicator selection criteria (RACER)*

Indicators should be selected to create a transparent monitoring framework for the circular transition and, therefore, following the RACER criteria: Relevant, Accepted, Credible, Easy to monitor, and Robust. However, experimental indicators can be encouraged even if not all the RACER criteria may be initially fulfilled.

- *Exploit a wide range of data and information sources*

In support of the monitoring framework, data sets are essentials and may consist of official statistics available at Europe and National level, other data produced at local level as well as by international sources. Together with statistics, policy information can be inserted in the monitoring to track qualitative changes and express their assessment. New data sources can also be used, such as the ones coming from the private sectors.

- *Ensure multilevel monitoring*

Different levels of governance and consequently different scales are involved in the transition. Stakeholders from global to local can contribute for the development of coherent metrics that capture the multiple dimension of the CE transition.

- *Allow for measuring progress towards targets*

The monitoring framework supports the progress to relevant policy targets and objectives, informing if the right policies are in place and well implemented or helping in identifying corrections or new policies if needed.

- *Ensure visibility and clarity*

A clear and effective monitoring framework will support policy makers and inform citizens and stakeholders. User-friendly communication channels should be identified and used as well as open data made fully and freely available.

The application of Bellagio chart principles brought to the identification of 7 key indicators that are at the basis of a comparative analysis carried on between France, Germany, Spain and Poland, that are the top-five economies in the EU. Italy resulted to be in the first position in Europe considering a combination of the 7 above-mentioned indicators: waste recycling rate; utilization rate of materials from recycling; resource productivity; waste production and material consumption ratio; share of energy from renewable sources in total gross energy consumption; repair of goods; soil consumption. As it is possible to see, the attention to urban areas is here absent, mainly focusing on resource consumption and waste management. Land take is the only indicator that connect this strategy with the local scale of policy-making.

3.5 The construction sector in Italy

In Italy the construction sector is characterized by a turnover that exceeds 400 billion euros/year, generating work for about 2.6 million people, that corresponds to about 12% of national employment. The construction sector relies almost exclusively into domestic production: 95.8% of the purchases made by construction companies are produced by the national production system, while only 4.2% are made up of imported products (Luiss Business School & MiSE, 2020). After the economic and financial crises of the early 2000's there are positive trends in the investments of the construction sectors and, specifically, in all the activities: redevelopment, new residential construction, new non-residential construction and public works (ibid).

As show in the following image, the construction sector is among the average performers in terms of adoption of CE practices in relation to economic savings, and it has been estimated that the adoption of CE managerial practices could lead to an annual GHGs emissions reduction of almost 1.9 MtCO2 by 2030, with the largest contribution coming from the construction sector that could contribute more than 45% (Energy & Strategy group, 2022). Among the most frequent CE practices adopted in Italy, the recycle and design for disassembly ones are the most addressed, while repurpose of taking back to the system and product-as-a-service are not really diffused. In the case of the construction sector, the recycling, designing out waste and repurposing are the most implemented CE practices (ibid.).

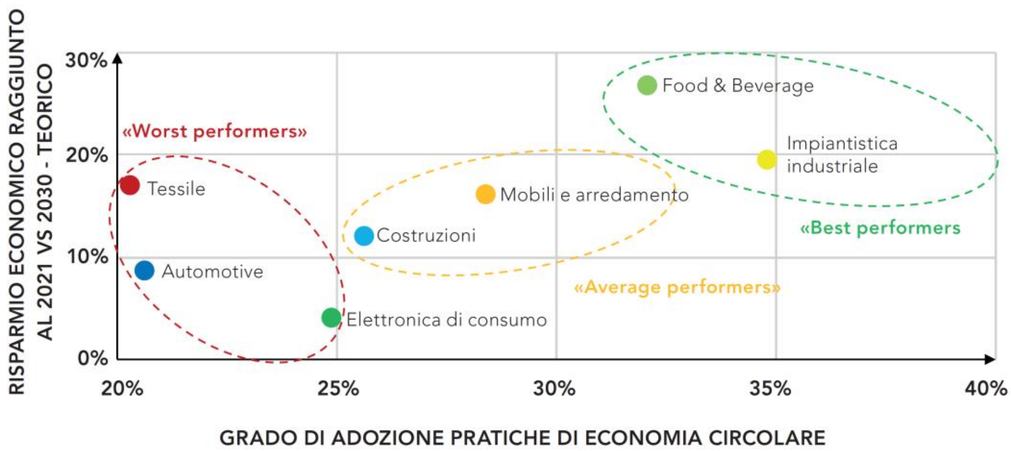

Figure 5: degree of adoption of CE practices in Italian economic sector. Source: Energy & Strategy group, (2022)

In the short period, three are the focus areas with the highest potentialities to embed innovative policies for the development of the sector: construction and demolition waste, materials and construction systems, integrated design (Luiss Business School & MiSE, 2020). In particular, in terms of waste production, in 2020 the construction sector has been responsible for the production of 48% on the total special non-hazardous wastage (ISPRA, 2022). The design for disassembly approach supported by the transition towards digital technologies like BIM is playing a key role in the transition towards circularity, offering an integrated assessment of buildings throughout the whole life-cycle and not only in the construction phase (Luiss Business School & MiSE, 2020). However, the Italian construction sector is still lagging behind in digital technologies, as well as in the technical and managerial skills of small and micro-enterprises, which are still particularly fragmented and with few multitasking working units (ibid.).

If speaking about construction, three are the domains that can be addressed to achieve the transition and innovation: **circular product, circular process, and circular platform**. This draws on the understanding the product-process construction paradigm does not suffice anymore in capturing the sector complexities and driving change toward concepts of holistic, democratic, and long-term sustainability, balancing between economic, environmental, and social aspects. Sector digitisation and the exploration of new integrated support tools, namely, digital platforms, become strategic in managing product and process complexities toward the transition to more sustainable business operating models (Gasparri et al., 2023). To enable the circular looping of finite materials and resources, the use of integrated digital platforms is key in managing resources and organisational infrastructures towards circular models of collaboration and value co-creation. The integration of product, process and platform domains is necessary to enable CE strategies implementation across construction scales and dimensions and requires the exploration of multi-disciplinary approaches and new holistic assessment (ibid.).

4. Case studies analysis for the construction sector in Italy

Among the biggest construction companies in Italy, the biggest one in terms of turnover is **Webuild**. Webuild SpA (formerly **Salini Impregilo SpA**) is an Italian industrial group specialising in construction and civil engineering. The company was formally founded in 2014 as the result of the merger by incorporation of Salini into Impregilo. Webuild is the largest Italian engineering and general contractor group and a global player in the construction sector.

The company is active in over 50 countries of 5 continents (Africa, America, Asia, Europe, Oceania) with more than 85,000 employees. Its experience ranges from the construction of dams, hydroelectric plants and hydraulic structures, water infrastructures and ports, to roads, motorways, railways, metro systems and underground works, to airports, hospitals and public and industrial buildings, to civil engineering for waste-to-energy plants and environmental protection initiatives. It takes first place in the water sector of the Engineering News-Record rankings, the benchmark for the entire construction industry. The company is listed on the Milan Stock Exchange and it is directed by Pietro Salini.

jIn terms of CE, there is a part of the company website that is dedicated to the topic and is listed among the company strengths. The complete list of success factors is reported below:

1. Responsible Behaviour: Strong ESG Standards
2. Solid ethical principles: integrity, fairness, transparency, sustainability;
3. Policy frameworks and governance systems that comply with the highest standards;
4. Rules and procedures to protect people, the environment and society in general;

5. Clear and transparent communication with our stakeholders;
6. **Climate protection and circular economy:** a robust framework for reducing greenhouse gas emissions in support of the circular economy;
7. Protection of labour rights and promotion of safe and secure working environments for all workers.

As it is possible to see, CE is listed together with climate protection in the mission and its main aim seems to be the GHGs emissions. The environmental protection has been a priority for the company since 2002, when they have been among the first industries adopting a specific Environmental Policy to monitor the performance. The company is committed to optimize the use of natural resources, promoting production and use methodologies aimed at their reuse and enhancement. In particular, they have a solid environmental track record: projects adopt the principles of the Circular and Green Economy, combining the principles of quality and "state-of-the-art" construction with the principles of environmental efficiency. Also in terms of management systems, the company is aiming at reducing the environmental impacts deriving from construction activities, by guaranteeing maximum transparency towards stakeholders about mitigation activities and performance.

In term of **circular process,** in 2022:

- the 52% of electric energy is generated by renewable resources (compared to the 2021 figure that was 35%);
- the GHGs emission from scope 1-2 has been reduced of 57% compared to 2017 values;
- Webuild reuses the 100% of extraction material.

For the Webuild Group, the development of the CE is mainly linked to SDG 12 and 13 - which are namely responsible consumption and taking actions to combat climate change and its impacts - and is one of the pillars of its sustainability policy. Webuild adopts practices aimed at minimizing the use of natural resources (including by reusing them) and intensifying the recovery of waste materials within the same work or in neighbouring areas. The circularity of the practices adopted by Webuild allowed the company to reduce waste produced by 46% in 2020 compared to 2019, while recovered waste is the 69% of the total waste generated. In addition, the volume of water consumed on construction sites has been reduces of 10% compared to 2019. In this regard, an innovative remote control system is being developed for the digital traceability of construction site water resources, in order to identify leaks and inefficiencies in real time and reduce their consumption as much as possible.

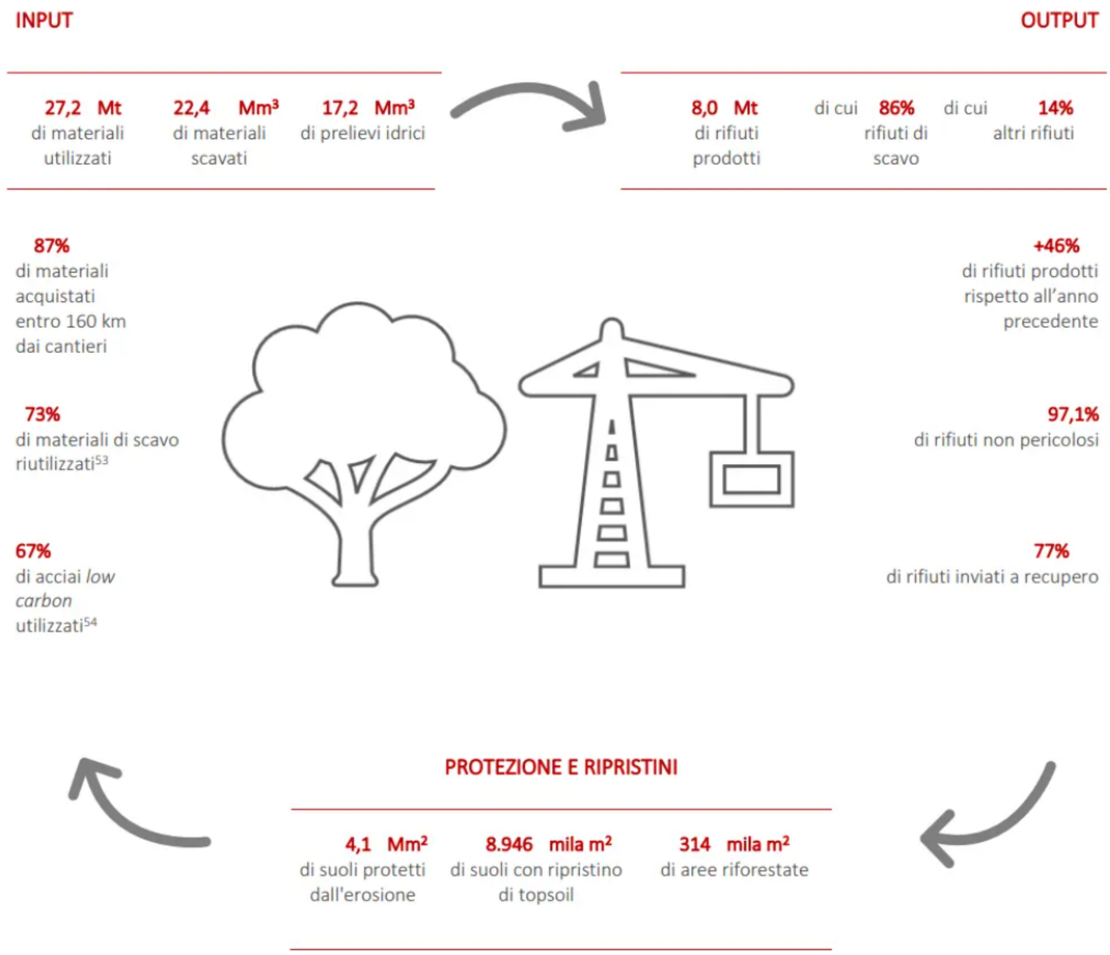

Figure 6: figures of CE process withing Webuild. Source: Webuild website

Webuild embraces the eco-responsible design, adopting an approach that considers the whole life cycle of infrastructures and considering the socio-environmental aspects in the diverse phases of projects development. The company has experience in adopting eco-design and eco-construction schemes, with about 50% of projects located in urban areas adopting LEED, GSAS or IS.

Among the examples, an Italian case study is the ENI Headquarters in Italy, which adopts the LEED Leadership in Energy and Environmental Design (Gold). The building auto-produces energy thanks to solar panels and saves the 40% of rainwater which is reused. All iron and concrete come from less than 200 km from the construction site and contain recycled content greater than 90% for iron and more than 5% for concrete. In the construction of the building all the indications of the Level(s) framework has been considered. Webuild also analysed the potential synergies between Level(s) and the LEED certification system, as both can be considered instruments of enhancement real estate in terms of sustainability. A mapping of the potential synergies came out for future optimizations in the case of coexistence of the Level(s) tool with other sustainability certification schemes. In order to achieve the result, a workgroup has been created with multidisciplinary skills to manage different topics like LCA, certificates EPDs, resource saving, etc.). The complex reached the Gold level of the LEED certification.

In terms of **products,** the Group developed a special optimized concrete mixes, characterized by a reduced cement content or the use of up to 65% recycled materials from other industrial supply chains. Also with regard to metal materials, the use of solutions with steel with a high recycled content is becoming increasingly popular: on the next start-up projects in Italy, Webuild aims to reach shares of over 90% of the recycled content.

In terms of **circular platform,** the use of digital technologies is fostered, especially through the use of BIM systems for the design and management of the construction phases, as well as as above mentioned, the digital traceability of construction site water resources. In the following, a synthetic image is reported, with the figure of the Company in terms of CE.

Acknowledgments

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地の塩、世の光

The Salt of the Earth,The Light of the World

【青山学院スクール・モットー】

AOYAMA GAKUIN UNIVERSITY PROJECT RESEARCH INSTITUTE
SDGs and Circular Economy Partnership Research Institute