Recycling perspectives of circular business models: A review

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Supplementary material

Table S1. Previous published review articles titled "circular business model" or "circular business model innovation"

Ref	Title of the article	Major findings	Identified research gaps/future research directions
Pieroni et al. (2019)	Business model innovation for circular economy and sustainability: A review of approaches	• Identified 92 approaches of business model innovation (BMI) and approaches were heterogeneous in nature, based on multiple theories, and primarily deviated from the traditional view of the business model canvas.	• Applying existing tools and methods for new areas that require specific gap fulfillment
Rosa et al. (2019a)	Circular Business Models versus circular benefits: An assessment in the waste from Electrical and Electronic Equipment sector	• In the e-waste sector, three major types of product-service system (PSS)-based CBMs were identified: product-oriented, use-oriented, and result-oriented.	• There is a need for a framework by which benefits of CE adoption would be realized among practitioners and stakeholders, as both practices and barriers (in the process of CE adoption) are present internally and externally to companies involving single or multiple actors.
Geissdoerfer et al. (2020)	Circular business	• Value capture is achieved by	• More investigation on business model

	models: A review	additional revenue from end-of-life products and materials and cost minimization from the material acquisition. The outcome of this strategy is environmental potential (e.g., the longevity of product/material and reduction in energy/material intake and waste output).	ecosystems integrating value network and business model portfolio to achieve holistic understanding on the tools for corporates that work and the setting of CE.
Salvador et al. (2020)	Circular business models: Current aspects that influence implementation and unaddressed subjects	• The importance of the top management's support and actions outside of the organization were found as the most addressed issues under the CBM research theme for increasing circularity.	• For the evolution of the CBM research theme, both investigations and partnerships are required from theoreticians and practitioners. Aspects related to CBM implementation are still early and require further attention.
Nußholz (2017)	Circular Business Models: Defining a Concept and Framing an Emerging Research Field	• There is a lack of coherent view and classification around resource efficiency strategies and business models as circular.	• In the future, companies would operate beyond a single life of the product using an extended connected network for value creation which might create the configuration of the BM to be more complex assessing the suitability of existing tools of linear business model in CBM development integrating

			resource efficiency and business model perspectives.
Centobelli et al. (2020)	Designing business models in circular economy: A systematic literature review and research agenda	• The role of the emerging digital technologies of Industry 4.0 should be implemented in the managerial practice and top management's commitments for the CBM transformation in companies.	• Influence of political initiatives and regulatory framework on the adoption of circular economy in a specific region or country. • Examining innovation patterns occurring at the company level.
Lewandowski (2016)	Designing the Business Models for Circular Economy-Towards the Conceptual Framework	• ReSOLVE framework developed by Ellen MacArthur Foundation was considered the primary basis for typology and categorization of the CBM context and focus.	• There is a need for a comprehensive conceptual framework for the circular business model supporting practitioners for CE transition.
Santa-Maria et al. (2021)	Framing and assessing the emergent field of business model innovation for the circular economy: A combined literature review and multiple case study approach	• Three key issues have been identified in the incumbent firms for circular business model innovation (CBMI), a) elements of the CBMI process, b) moderators of the CBMI process, and c) effect of CBMI (that consisted of systemic change and social performance).	• Future research should focus on critical elements of the CBMI process and their sub-elements such as a) sustainability strategy as an antecedent of CBMI, b) top management role, and c) organizational change management. Moderators of the CBMI process include organizational culture and structure, organizational

			inertia, agile/adaptable, and CBMI uncertainties.
Upadhyay et al. (2019)	Investigating “circular business models” in the manufacturing and service sectors	• Quality development of resources, improved product improvisation, new market opportunities, and increased competitive advantage are some of the critical issues facilitated by CBM (in the manufacturing and service sector).	• The role of CE in the manufacturing and service sector is an under-explored research area.
Bigliardi and Filippelli (2021)	Investigating Circular Business Model Innovation through Keywords Analysis	• The issues of collaboration, circular entrepreneurship, agro-waste valorization, and digital technologies 4.0 were the main research-related keywords in the CBMI context.	• Knowledge sharing phenomenon (in the collaboration of actors) in circular business model (in CE in general) development using open innovation is poorly investigated.
Salvador et al. (2021)	Key aspects for designing business models for a circular bioeconomy	• Product and material take-back systems of traditional products with long product lifespans could be used as inspiration for designing reverse cycles and business model development in the context of Circular bioeconomy (CBE).	• Business model experimentation of bio-based products based on PSS has an opportunity.
Hultberg and Pal (2021)	Lessons on business model scalability for	• From the business model design, four different	• More detailed identification is required for

	circular economy in the fashion retail value chain: Towards a conceptual model	perspectives have been proposed as part of the CBM activity areas, which were: a) increase the collection volume of used apparel, b) increase the resold volume of used apparel, c) increase volume the apparel made from recycled post-consumer textile fibers, and finally, d) implement design strategies for cyclability. These perspectives have been drawn from the notion of "closed" and "open" business models, along with efficiency-centered and adaptability-centered strategies.	specific resources and capabilities of the scalability approach and CBM activity areas.
Abideen et al. (2021)	Leveraging Capabilities of Technology into a Circular Supply Chain to Build Circular Business Models: A State-of-the-Art Systematic Review	• Food, energy, manufacturing, and chemical were the primary sectors that were focused on within the Circular supply chain (CSC) research theme; however, limited research was done in healthcare, fashion, agriculture, and electronics sectors. • Circular business models have been given less attention.	• Green impact, life cycle assessment, implementation barriers and challenges, and the potentiality of circular business transition are some topics that require further attention.
Bocken et al. (2019)	A Review and Evaluation of Circular Business Model	• To have greater uptake of the CBMI tools and CE operationalization, some of the critical	• A further empirical investigation is required to understand the complexities of

	Innovation Tools	issues that need to be done include interdisciplinary collaboration for tool development, the creation of accessible tool guidance, and transparency of tool development. • Business cases should have more inclusion of positive environmental and societal impact.	actual business model innovation processes, and in such context, a longitudinal ethnographic and action-type research approach can be taken. This research area could overcome specific organizational barriers and identify best fitting business models.
Lüdeke-Freund et al. (2019)	A Review and Typology of Circular Economy Business Model Patterns	Repair and maintenance; reuse and redistribution; refurbishment and remanufacturing; recycling; cascading and repurposing; and organic feedstock were identified as the main CBM patterns.	• In circular economy business model (CEBM) design, customer preference (using and owning products or services) is not considered exclusively, and the identification of causes underpinning such practice requires further understanding. Also, it is worthwhile to investigate how such businesses (without considering customer preference) effectively attain their performance targets.
de Kwant et al. (2021)	The role of product design in circular business models: An analysis of challenges and	• From linear to a sustainable circular economy, manufacturers need to focus on two critical levers in the design and	• Lack of government policy on CE and CBM may result in a conflict of interest within companies and misaligned

	opportunities for electric vehicles and white goods	innovation space, a) business model and b) product	profit-sharing across the value chain. Such discrepancies might be mitigated when there is a convenient understanding of CBM focusing on environmental degradation. In other cases, the trend of the linear model will persist. Within such a narrow and specific focus, future research should identify the impact of policy and regulation on cost, revenue, channels, customer segments, and customer relations.
Galvao et al. (2020)	Towards a value stream perspective of circular business models	• From CBM perspectives, company production is interconnected with environmental aspects (use of renewable natural resources, protection of non-renewable natural resources, reduction of pollutant emissions and waste), supply chain (with various suppliers), social aspects (community development, consumer education, human capital improvement), consumer use,	• Application of system dynamics simulation understanding the interactions of value streams across the elements/contexts of company production system.

		energy (non-renewable or non-clean energy sources, renewable and clean energy sources) and economic aspects (financial and reputation).	
Rosa et al. (2019b)	Towards Circular Business Models: A systematic literature review on classification frameworks and archetypes	• Circular-based plans and subsidies depend solely on government initiatives, and CBM archetypes could be helpful in such instances.	• There is a lack of practical evidence on the transformation of linear BM into a CBM.

Table S2.1. Elements of CBM adoption or implementation strategies

Elements
• Applicability of existing tools and methods (e.g., business model canvas) for business model innovation • Framework for adoption among stakeholders and practitioners in a single or multi-actor environment • Specific tool development for corporate firms integrating value network and BM portfolio • Balance complex value creation network • Organizational change management • Open innovation • Complexities in business model innovation process • Focus on environmental degradation • Design for recycling • Design for end of life • Product design targeting recycling • Industrial symbiosis • Flexibility of additive manufacturing and 3D printing • Product service system • Collaboration for technological innovation • Recycling technology • Cooperative business organization • Downstream recycling technology and infrastructure • Use of decision-making models • Availability and applicability of social impact tools • Techno-economic flowsheet • Eco-innovation

• Information sharing • Remanufacturing monitoring system • Green human resource management • Zero-emission strategy • Green product innovation • Decentralized recycling facilities • Deposit recovery system • Research and development (R&D) • Purchasing efforts • Use of recycled material as raw materials • Sizeable commercial recycling infrastructure • Smart product-service system • Online-product return strategies (recycling platform) • resource conservation-related education to customers • Social campaign • Business model application • Business finance • Optimum recycling procedures • Focus on poor market structure • Leadership in metal recycling initiatives • Develop separation and segregation technology • Development of feasible recycling system • Implementation of support structure for recycling

Table S2.2. Elements of (organizational) Performance assessment

Elements
• Constant examination of innovation pattern in firms • Top management role • Attitude and perception around recycling-oriented startup investment • Culture and structure of organization • Motivations for including SDG strategies via circular business model innovation • Scalable resource and capabilities • Interactions of value stream • Assessment of losses and residues in production system • Capability of material reuse • Enterprise information systems (EIS) • Integration of performance assessment tools with CBM • New collaboration method • Environmental commitment • Emission reduction strategies • Stakeholders' interest • Use of decision-making models • Carbon-neutral company • Job creation ability • Transportation cost reduction • CBMI uncertainties

• Organizational inertia • Cost of operation and systems • Increase recycling capacity

Table S2.3. Elements of indicators

Elements
• Recycling rate • Lifecycle assessment • Green impact • Waste generation estimation • Material recovery rate • Productivity (industrial output) • Reduced energy consumption • Recued packaging waste • Renewable raw material uses in production • Energy efficiency • Emission reduction in production process • Use of recycled materials in production • Carbon footprint accounting

Table S 2.4. Elements of Initiation and progress of CBM transformation

Elements
• Business model experimentation • CBM design • Customized product development • Implementation of Net-zero-waste processing • Urban mining • Low-grade material streams • Focus on non-traditional waste material (e.g., non-household waste) • Distributed recycling scheme • Robust forecasting model • New market opportunities • Environmentally sound and economically feasible recycling framework • Clarification of business model typology, definition • Setting key performance indicators • High cost of recycled material acquisition • Initial cost of investment • Length and breadth of practical CE coverage for business • Energy-intensive recycling process

Table S2.5. Elements of sectorial product and material-centric approach

Elements
• Durability and longevity • Light weight products

• Biodegradable materials • Biogas production • Bio-based products • Presence of hazardous materials • Impact of design dissimilarities in recycling • Eligibility of 2nd life application • Availability of auxiliary components • Predictive capabilities of equipment failure • Cost effective energy storage system • Reparability • Material composition in product • RFID-tag based product • Product traceability • Circular product design with recycled materials • Product renovation • Product redesign with bio-based materials • Standardization and warranties for recycled products • Quality of the recycled materials • Material substitution • Keeping material in resource cycle for longer • Minimization packaging impact • Stockpiling of used products • Ease of disassembly • Purity of recycled materials • Standard recycling rate • Product recyclability • Incentives to remanufactured products • Price competition and quality assurance of recycled material • Poor product design

Table S2.6. Elements of data and digitalization

Elements
• Data collection, management, and exchange of information • Cloud-based manufacturing system • Industry 4.0 • Internet of things (IoT) • Buildings as material bank • Material passport • Product embedded information devices • Recycling-focused product lifecycle information systems (e.g., Inverse Manufacturing Product Recycling Information System, Recycling Passport, Integrated Recycling Data Management System) • Sensors and internet protocols • Universal product codes • 2-D barcodes • Additive manufacturing

• embedded telematics for end-of-life (EoL) decision-making • Intelligent sorting system • circularity passports • Monitoring and reporting system for reverse logistics • Transparency of data – actual recycling rate vs. recycler's audit

Table S2.7 Elements of Circular supply chain

Elements
• Competition • Reverse-cycle activities for recycling • Collaboration • Take-back schemes • Stakeholder analysis • Product-service system • Servitization • Gap-exploiter model • Trans-sectoral recycling partnerships • Third-party waste collection firms • Third party recycling firms • Supplier diversification • Retail Recycling Mode • Repo Recycling Mode • Own asset recovery and recycling • Regional and local supply chain • Impact of complex supply chain network on environment • Waste-oriented circular value chain • Network topology • Minimize value leakage

Table S2.8. Elements of stakeholders' orientation and perspectives

Elements
• Customer preference • Customer relations • Customer segments • Customer interaction for return flow or resources • Original equipment manufacturer • Quality requirements of customers and manufacturers • Compatibility of stakeholders • Consumer awareness • Manager's perception about business as cost-driven and reactive model • Community-led organization • Willingness to pay for recycled materials/nutrients

• Consumer recycling behavior • Environmental awareness • Participation of original equipment manufacturers • Intention-behavior gap • Willingness to participate in recycling • Sustainable consumption practice • Design, testing, and pilots • Co-creation with customers • Socio-economic characteristics of the customers • Shared producer responsibility • Customer perception on products made with recycled material/refurbished products • Complex stakeholder structure in supply chain • Lack of knowledge sharing platform • Sharing of intellectual property rights (IPR) • Waste collection system • Cooperation and coordination of waste generating companies and product manufacturers • Manufacturers' recycling intentions • Incentives for recycling • Social norm around recycling • Value exchange for recycling

Table S 2.9. Elements of policy and regulations

Elements
• Regional regulatory framework • Impact of government policy on profit-sharing model across value chain • Impact on cost, revenue, and channels • Applicability and enforcement of EPR • Technical guideline for recycled material use • Scope of recycling scheme • Product certification and standardization • Incentives • Regulatory intervention on taxation strategy • Joint Producer Responsibility system • Environmental product declaration • Governance • Recycling regulation • Extended producer responsibility (EPR) • secondary market development • Incentives on recycling targets (at regional level) • Recycling regulation targeting minimized packaging impact • Conditional cash transfer as financial incentives • Incentives to actors involved in resource recovery • Mandatory joint collection and recycling scheme • Voluntary certification scheme for waste treatment • Provision of public share in recycling businesses

• Point reward system • Lack of knowledge about recycling program

Table S 2.10. Elements of recycling focused CBM research direction

Elements
• Interdisciplinary investigation and partnership • Specific focus on manufacturing and service sector • Product-service system for bio-based products • Longitudinal ethnographic and action-type research approach assessing best fitting BM • System dynamic simulation on production system • Lack of practical evidence from liner to circular BM • Impact of additive manufacturing technology on business model • Modular integrated construction • Metal recycling technology • Multi-disciplinary theoretical approach for decision making model • Social LCA (SLCA) and socio organizational LCA (SOLCA) • Efficient payment mechanism for reverse logistics activities