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A Study on Eco-Innovation and Sustainable Development of Circular Economy in Rwanda.

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Abstract

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The latest developments of circular economy have shown its importance and relationship with sustainability as natural resources become increasingly scarce. Rwanda, among other developing countries, encounters rapid urbanization and industrialization, which in turn have a significant relationship on the generation of various wastes. These include food waste, paper waste, metal & glass waste, e- waste, etc. This study agrees that inappropriate waste management is favored by the existing industrial business model, called the linear business model, that designs products to be disposed of at the end of their life cycle.

To overcome the challenges related to waste generation, the transition from a linear to a circular business model is paramount. This study, therefore, discusses the development of a closed-loop of material flow called the circular economy along with two different influential factors, namely eco-innovation and green supply chain management.

This study uses partial least square structural equation modeling to analyze the relationships between constructs. The findings show that industrial activities across the country are not aligned with the circularity of materials due to several reasons. These include the lack of industrial-technological capabilities, insufficient practices of product eco-innovation, marketing & organizational eco-innovation, the lack of market demand, and insufficient activities to keep track of products and material flow. These act as some of the main barriers in achieving circular economy principles. On the other hand, process eco-innovation practices of manufacturing firms and environmental regulations positively influence circular economy and eco-innovation activities, respectively.

Therefore, this research recommends the government of Rwanda, policy makers, and other environmental protection stakeholders take immediate actions and raise awareness among manufacturing firms across the country to fully understand the necessity of a paradigm shift from an industrial linear to a circular business model.

Keywords: Eco-innovation, circular economy, circular supply chain management, sustainability.
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Chapter 1. Introduction

1.1. Study Background

The literature about smart city, eco-innovation, and circular economy concepts has shown significance in research and academia for the past two decades, mainly for their importance in developing city, human, technology, infrastructure, and environmental protection.

According to a United Nations publication, the world’s population is increasing exponentially, and is estimated to reach 9.7 billion in 2050. Additionally, 70% of the population will be located in towns by that time (UN, 2018). The urban development beings forth new challenges to the city due to increased population, industrialization, and economic development. Monzon (2015) highlighted city challenges according to their locations including those related to governance, economy, mobility, people, and living.

The Rwandan population is increasing exponentially. The United

Nations databank (UN, 2015) shows that the annual population growth rate in Rwanda is 2.4%(2010-2015) with an annual urban population growth rate of 2.8%. Against this background, urbanization induces challenges in the city that did not exist before. The population growth causes increased product demand, and as industrial production increases, more natural resources are extracted from nature.

Rwanda developed and implements environmental protection policies that respond to environmental and climate challenges, and natural resources management for economic growth and sustainability (MoE Rwanda). Rwanda aims to achieve the principles of Circular Economy(CE) as a smart city component by establishing, in 2019, a joint national CE forum that gathers together environmental policymakers, academics, industry, and civil society (FONERWA, 2019). This coalition ensures that technology, industrial activities, and other related services embrace the best practices for environmental protection and green production. Moreover, Rwanda is a member of the African circular economy alliance, which has objectives to share best practices on the development of circular economy projects and raise awareness about circular economy across member states.

Circular economy initiatives in Rwanda are at their initial stages and need further development (MoE, 2019). For instance, the country has a single e-waste management and dismantling facility, plastic recycling projects, refurbishing electronic equipments, water reuse projects, etc.

1.2. Motivation

In order to attain the environmental protection goals, related initiatives are being implemented in Rwanda. However, those complying with circular economy principles are scarce. As a country with abundant natural resources and a fast growing population, Rwanda can generate large amounts of waste in the near future if there is no strong commitment to adopt a new circular business model. Circular economy principles cannot be achieved by government-enabled initiatives only but also by the private sector and public engagement.

The global innovation index 2020 ranked Rwanda 91. Among major barriers that can affect environmental protection mechanisms are lack of innovation & industrial design capability, technology-related issues, and other factors that lower the country's ecological sustainability & environmental performance. This study, therefore, is motivated to provide insights on the circular economy ecosystem in Rwanda and how it can be influenced by both eco-innovation activities of manufacturing firms and circular supply chain management.

1.3. Problem description

The scarcity of natural resources, environmental degradation, inefficient waste management, pollution, among others, are categorized as environmental challenges of smart city development.

Angelidou et al. (2018) analyzed environmental sustainable challenges from which the approach to mitigate environmental pollution by reducing waste is paramount and requires technology and innovation capabilities and the necessity of waste recycling awareness among citizens.

The population shift from rural to urban areas constitutes the main reason for environmental degradation and waste generation. Y.C. Chen (2018) discusses the effects of urbanization on wastes generation, and shows that industrialization with increased population has a significant relationship on the production of food waste, paper waste, and metal & glass waste. Increased waste generation can induce problems including sorting, collection, and transport to disposal sites. Non-professional waste management causes citizens to collect, dispose and sort waste under hazardous conditions (Josh et al., 2016) which in turn can complicate further waste management.

Inappropriate waste management is favored by the existing industrial business model, the linear business model, that designs products to be disposed of at the end of their life cycle. The overall process to extract raw materials, manufacturing, product distribution, and the use and disposal of wastes has a negative impact on the environment (Garza-Reyes et al., 2019), (Horvath et al., 2018). The major challenge of the existing industrial linear business model occurs at the disposal of waste (Horvath et al., 2018). Moreover, the linear business model seems to be against resource conservation and increases their depletion in nature (Michelini et al., 2017).

To overcome the challenges related to environmental protection, the transition paradigm from the linear to circular business model is paramount. It introduces a closed loop of material flow (Garza-Reyes et al., 2019) from extraction to its reuse capability. Circular economy as a principle minimizes raw materials utilization, reduces waste, and keeps the product value (Suárez-Eiroa et al., 2019) through a circular business model. Stahel (2013) explains the logic loops of circular economy and defines it as a means to reduce resource extraction, improve waste management, and minimize environmental impairment caused by industrial activities. The principles of circularity cannot be achieved in the absence of improved industrial design capability, eco-friendly manufacturing processes, monitored product supply chains, including product distribution and waste collection. Furthermore, there are a broad range of barriers to achieving circular economy principles, including those related to finances, skills for product eco-design, limited acceptance of consumers, waste management, lack of policy, etc. (EIO, 2017).

On the other hand, the benefits are increasing and the successful factors of circularity are many but not limited to leadership of firm's owners, eco-design capability, policy & regulations, and acquisition of circular economy information management system, etc. (Moktadir et al., 2020). De Jesus & Mendonça (2018) discuss the transition towards a circular economy and identified technical, economical, and institutional capability as the main drivers of circular economy. At the same time, the technology, capital requirement, absence of conducive legal framework, and limited innovation activities are the major barriers of firms in achieving and adopting a circular business model.

Eco-innovation capability for circular economy combines innovative activities to design better products that are possible to be reused again and again, these activities also are necessary for waste reduction, waste collection, recycling, as well as the re-processing of new products. In addition to the importance of eco-innovation, it has a potential influence on economic growth (Mazzoni, 2020a); thus the concepts of circular economy and eco-innovation are interrelated at some point. Maldonado-Guzmán et al., 2020a recognize eco-innovation as a mechanism for linear to circular economy transition.

1.4. Research objectives

This research aims to provide a wide understanding of the circular economy as a component and a measure of a sustainable smart city in Rwanda, particularly by analyzing the influential mechanism of eco-innovation activities performed in manufacturing firms toward the circular economy paradigm shift. Considering the objectives of this study and the problem statement, the following research questions are formulated.

RQ1: Are the eco-innovation practices of manufacturing firms impacting circular economy principles in Rwanda?

RQ2: What are the influential mechanisms of green supply chain management to attain the principles of circular economy in Rwanda?

1.5. Research outline

This study consists of five chapters. Chapter 1 introduces the study background and motivations. It also describes the identified problem related to the adoption of a circular economy in Rwanda. Chapter 2 analyzes existing theories that support the assumptions and hypotheses of this study. Chapter 3 introduces the model and methodology used for data analysis. Chapter 4 discusses the findings and provides implications related to this study. Chapter 5 consists of a conclusion and briefly summarizes this study.

Chapter 2. Literature review

2.1. Circular economy and smart city

The smart city concept has gained attention around the globe in the last two decades due to increasing city populations. Researchers contribute to defining the term smart city in different ways, but the common definition includes sustainability, the well-being of people, the use of technology that facilitates tasks, or the city where the interaction of technology and people is made possible and easier. The International Telecommunication Union (ITU) defines the smart city as *the innovative city that leverages Information Communication Technology (ICT) for the well-being, efficiency of city services, and competitiveness. Moreover, it must be a city that ensures socio-economic and environmental sustainability* (*ITU-T*).

According to the definitions, the goal of smart city is to achieve sustainability as the population grows (Petit. B et al., 2018).

According to a United Nation report (2015), cities are expected to occupy 70% of the global population by 2050. Cities are required to provide a sustainable solution through city planning initiatives. Although the shortcomings of smart city planning are numerous, such as budget shortage and other development and organizational challenges (Angelidou, 2017), the experience and best practice to develop smart cities is promising and shows that the future of cities can be sustainable.

Smart city master plan indicates the major components that constitute a city that protects and conserves the environment as well as natural resources. The environmental aspect of the smart city involves the new concept of circular economy, which introduces a new sustainable business model focusing on giving a value to a product right after its life cycle. It is, however, defined as a closed loop of material flow with the principles to reduce, reuse, recycle, and recover product material (Kirchherr et al., 2017). Currently, the scarcity of natural resources is accelerated by the take-make-dispose economic business model. The city planners propose the practice of minimizing the material residues and wastes by re-using, refurbishing, and recycling the products.

The relationship between smart city and circular economy is observed in natural resources and waste management. The circular economy brings forward environmentally friendly initiatives (Petit. B et al., 2018a), which are in line with the goals and objectives of the smart city (achieve social, environmental, and economic development) and the practices of circular economy helps the city to analyze the environmental impacts as well as the strategies that extend urban sustainability (Petit. B et al., 2018b).

However, it requires much attention to transfer circular economy concepts into cities. Santonen et al. (2017) argued the complexity of circular economy at the city level due to the variety of stakeholders to be involved. Despite those challenges and complexity, the circular economy offers a thriving city where economic productivity is increased and where the city is more resilient.

In principles, circular economy in the smart city exhibits product design capability among manufacturing firms in order to produce durable products by minimizing the exploitation of raw materials. However, Hollander et al. (2017) discussed the basic distinction to overlook between eco-design and circular economy product design adapted with new methods and strategies that prevent the product from becoming obsolete.

The product design stage determines whether the product raw materials will be re-used or re-processed again in the future. For this, eco-innovation activities of firms play a crucial role toward a circular paradigm shift. Therefore, the design capability of firms results in long term usable and durable products, or products that are able to be extended and upgraded or otherwise those with a high capability to be refurbished, repaired or re-manufactured.

Additionally, the design phase is able to provide practical guidance strategies that promote sustainable product design solutions that accelerate the adaptation of the circular economy (Mestre & Cooper, 2017). In a general sense, the circular economy is expected to slow down the need for new products. The product design capability expands the functionality to establish a continuous flow of resources (Bocken et al., 2016). To extend the lifetime of a product, it must be designed in a such a way that its disassembly is made easy (Van den Berg & Bakker, 2015).

2.2. Circular economy and eco-innovation

In the context of sustainable development, innovation itself is described as a new way to commercialize solutions by means of technologies (Dutz & Sharma, 2012). Furthermore, the term eco-innovation hereafter exchanged with green innovation (Leal-Millán et al., 2017) has attracted attention in the last two decades, mostly after being considered a critical factor in achieving sustainability (UN, 2015). It consists of exploring new methods in organizational processes that lead to minimizing environmental risks.

Vence et al. (2019) define eco-innovation as a driver to reduce environmental degradation. Green innovation fosters sustainable growth through technological and other practical approaches that result in environmental improvements (*Green Growth and Eco-Innovation [GGI), 2021*). Leal-Millán et al. (2017) also describes green innovation as the one that creates products and processes by considering environmental protection mechanisms. It provides new socio-technical solutions that protect the environment and retain the value of products (De Jesus & Mendonça, 2018). Similarly, Carrillo-Hermosilla et al. (2010) also define eco-innovation as a tool to minimize environmental impacts induced by product manufacturing activities and consumption. In general, green innovation is ones that improve environmental performance.

Mazzoni (2020b) explains business oriented types of eco-friendly innovation such as market eco-innovation to promote environmental friendly products, business model eco-innovation that focuses on user preferences of eco-friendly products, and systemic eco-innovation designed to improve environmental performances across all economic perspectives, etc.

The current dynamics of green innovation extend its importance not only to environmental protection but also to the economic growth of a firm which relates to circular economy objectives. Pereira & Vence (2012) studied the factors that foster green innovation and how important it is to the extent that it can be a key strategy to allow the businesses to make improved economic and environmental profits and so that growth is certainly sustainable. Additionally, Bossle et al. (2016) described the major factors that drive eco-innovation to improved environmental performance divided into external and internal factors. These are considered technology, regulatory & environmental managerial concern, and environmental protection capability.

To achieve a sustainable transition from a linear to a circular economy, the inter-relation of eco-innovation and closed loop material flow is paramount and has to be studied further as eco-innovation is an instrumental factor in achieving a circular economy (Kiefer et al., 2021). Researchers contribute to explore the relationship between circular economy and green innovation as a component that leads to systemic change. It is urgent to understand how eco-innovation is able to drive the emergence of a circular economy (de Jesus & Mendonça, 2018). The importance of green innovation to accelerate the circular economy transition gives the potentials towards resource efficiency through product reuse as well as recycling of materials. Similarly, Vence et al., (2019) state the way circular economy affects the efficiency of resources via eco-innovation. EIO (2017) differentiated the types of eco-innovation for the development of a circular economy. Among them, this study employs the following:

1. Product design eco-innovation: It contributes to material recovery options to ease product maintenance, remanufacturing, and recycling.

2. Process eco-innovation: This type of eco-innovation brings forward the facts to generate zero waste and emissions during production.
3. Marketing eco-innovation: To promote the usage of eco-friendly products.
4. Organizational eco-innovation: Consists of managerial methods and firm practices that lead to eco-innovation

Maldonado-Guzmán et al. (2020b) unfolded two concepts of circular economy and green innovation in the automotive industry and found that green innovation mechanisms applied to product development and management activities have a significant relationship to the development of circular economy in the automotive industry.

Not only during the production stage, but the eco-innovation activities are also supposed to contribute to all stages of the product life cycle. In other words, eco-innovation is integrated with resource extraction, product manufacturing, product consumption, waste management (e.g.: sorting chemical wastes, food, general wastes, and identifying recyclable and non-recyclable wastes). Eco-innovation activities performed to improve the circular economy are indicated through different categories listed by (Kiefer et al., 2021), including the eco-innovation capacity of a nation or organization (economic competitiveness, green technology R&D capability, sustainable management). Another category consists of environmental support for green innovation, under which the circular economy performance is indicated by the availability of regulation to implement and conduct environmental protection initiatives. The category of eco-friendly activities brings together the economic influences that lead to the protection of the environment along with the business model to adopt green technologies. The waste management and circular economy categories present the advantages of recycling different wastes such as bio-chemicals, e-wastes, and others.

2.3. Circular economy and consumer perceptions

The circular economy model introduced multiple opportunities for environmental protection, particularly by changing product consumption patterns. Customers have different perceptions of using remanufactured products due to various factors. Their preferences, however, determine whether the principles of circular economy will be achieved in the near future. Remanufacturing is defined by Wei et al., (2015) as a process to collect used products and make from them new and similar quality products through various operations such as cleaning them, adjusting them, replacing old parts, etc. Remanufactured products herein exchanged with refurbished products are the ones that are industrially re-processed in order to ensure and retain product quality (Almefelt & Rexfelt, 2017). There is no doubt that customers may be worried about the quality of the remanufactured products and this mind-set can be a great barrier to the adoption of circular business model.

Acceptance of refurbished products is paramount in measuring a successful circular business model (Singhal et al., 2019), for the lack of consumer acceptance can hinder the diffusion of a circular business model (Camacho-Otero et al., 2018). Many existing research has kept the focus on the development of circular economy as a new way to protect the environment, exploring the critical drivers that can influence its adoption, such as technological capability and government/regulatory framework. Despite the scarce amount of research contributing to remanufactured product consumption, topics on understanding the relationship between circular economy and customer product preferences are rising (Nasution & Tjhin, 2020). This shows the importance of keeping track of the customer's point of view and evaluating and examine their intentions about the use of circular products.

Different factors that influence customer's intentions to purchase remanufactured products can be overseen from their attitudes and beliefs about these products. Moreover, customer's individual interests such as product price comparison, governmental incentives that encourage the customers to purchase these products, and the extent to which the customers think it is risky to purchase the products.

Industries are supposed to engage themselves in environmentally friendly manufacturing as an emerging approach to attaining a circular business model (Singhal et al., 2019) by keeping track of the product life-cycle. This approach also develops sustainable practices that maintain the scarcity of resources, provide better solutions to increased product demands and contribute to the required transformation toward a circular business model. Additionally, industrial designers have to consider that the lack of consumer acceptance toward the usage of refurbished products is among the main barriers to achieving circular economy principles (Camacho-Otero et al., 2019).

There is no doubt that consumers prefer to purchase a durable product so the competitive advantages of refurbished products must outweigh those of normal products, which in turn, can reduce the risks and worries to buy remanufactured products. Among other factors that may influence the customer's behaviors to purchase refurbished products, green awareness also plays a crucial role. Singhal et al. (2019) explained that it positively impacts the behaviors of human being's when it comes to environmental protection. In addition to this, people are willing to have refurbished products when they are aware of available environmental profits (Wang et al., 2018). Therefore, customers themselves determine the extent to which their own assessment of the use of refurbished products turns into advantages or disadvantages. The more positive the attitudes they have, the higher the tendency to use these products (Singhal et al., 2019). At the same time, the market strategy for remanufactured products is of great importance. Developing a business model to sustain these products in the market will attract various customers.

2.4. Practices for circular business model

This study considers multiple dimensions that the manufacturing companies can use to develop and implement circular business models. Business model can be defined as a design for a successful operation of business that is capable of changing the market structure (Seidenstricker et al., 2014). Similarly, a circular business model is the rationale of an organization that creates, delivers, and captures the value of a product by narrowing or slowing down the extraction of raw material from the environment. Generally, new business models are developed and designed during economic uncertainty, during industrial transformation such as introducing new technology to improve production where the firm invests to gain new customers and dislodges the competitors. Furthermore, the business model is subject to change when firms need to fit customer preferences, especially for a new product. Similarly, during the product innovation stage, the firm can redesign a new business model for that specific product so that it meets customer requirements. Therefore, a circular business model interacts with marketing eco-innovation to promote the usage of eco-friendly products. Additionally, the circular business model helps create values for target customers (Osterwalder & Pigneur, 2010) since factors that improve customer value creation include performance of the product, technology features, how new the product is introduced on the market, the product design, and its cost & convenience.

Chapter 3. Research methodology

3.1. Theoretical structural model and hypotheses

3.1.1. Eco-innovation and circular economy

The initial part of this research develops a theoretical structural model that contributes to exploring the relationship between circular economy and green innovation as a component that leads to a systemic change. It is urgent to understand how innovation is able to drive the emergent need for a circular economy (de Jesus & Mendonça, 2018). The importance of eco-innovation to accelerate the circular economy transition gives the potentials towards resource efficiency through product reuse as well as recycling of materials. Another part explores acceptance of refurbished products as an important instrument towards a successful circular business model by studying different factors that influence the customer’s intention to purchase remanufactured products.

Advanced understanding of relationships between circular economy and eco-innovation brings about critical environmental factors that are relevant to the circular economy paradigm shift. (Cainelli et al., 2020). EIO (2017) differentiated the types of eco-innovation for the development of a circular economy, defining product eco-innovation which contributes to material recovery options to ease product maintenance, remanufacturing, and recycling. Hence according to Rodriguez & Wiengarten (2017), product innovation refers to the degree of newness the product possesses compared to existing product design and capability. Process eco-innovation, which brings the facts to generate zero waste and emissions during production, also makes the production more efficient (Andersen, July 17, 2). Marketing eco-innovation aims to promote the usage of eco-friendly products. Similarly, García-Granero et al. (2018) used these types of eco-innovation to categorize eco-innovation performance indicators and according to his study, product eco-innovation describes the changes in the production of goods or services towards a new product characteristic or technical specification. Process eco-innovation reduces wastes by increasing the quality of the product.

Table 3.1: Types of eco-innovation

Types of EI	Description	References
Product EI	• Gives changes in the production of goods and contributes to material recovery, remanufacturing, and recycling. • It introduces a new product with improved characteristics. • It focuses on product life cycle in order to reduce environmental impacts.	(EIO, 2017), (García-Granero et al., 2018), (Bossle et al., 2016),(Triguero et al., 2013), (Rodriguez & Wiengarten, 2017), (Cheng & Shiu, 2012), (Leitner et al., 2010)
Process EI	• Introduces strategies that generate zero waste and increases product quality during efficient production.	(García-Granero et al., 2018), (EIO, 2017), (Bossle et al., 2016), (Triguero et al., 2013), (Cheng & Shiu, 2012)

	• It develops products and services that have a positive impact on the environment.	
Marketing EI	• Promotes eco-friendly products and product delivery. • They offer different technological, environmentally solutions to existing products.	(EIO, 2017), (García-Granero et al., 2018), (Triguero et al., 2013)
Organizational EI	• Involves firm's practices and implementations that lead to eco-innovation. • Focuses on managerial methods that close the loops to increase resource efficiency. • Organizational commitment to implement new form of eco- innovation management.	(Triguero et al., 2013), (EIO, 2017), (Cheng & Shiu, 2012)

Marketing eco-innovation focuses on product delivery caused by new product design. This definition, however, shows the inter-relationship between marketing eco-innovation and product design eco-innovation. Organizational eco-innovation intends to improve a firm's routines and practices that lead to innovation. It introduces new organizational implementations that aim to reduce negative environmental impacts caused by production (Triguero et al., 2013). Table 3.1 describes the types of eco-innovation focused on in this study.

Existing studies explore the factors that influence circular economy. However, the focus is mostly on eco-innovation as an ecosystem. This study, therefore, contributes to unfolding the eco-innovation and provides influential mechanisms of different types of eco-innovation to circular economy principles.

The use of clean raw material during production lowers environmental impact, which constitutes one of the measurement indicators of product eco-innovation (Doran & Ryan, 2016; García-Granero et al., 2018). Similarly, different studies have argued numerous factors that identify firms that perform product eco-innovation to improve the quality of goods, products, or services, and those related to circular economy indicate the ability of manufactured products to be recycled (Dalhammar, 2016; Rodriguez & Wiengarten, 2017). Minimizing the number of components that constitute a product is also a best practice for resource efficiency (Doran & Ryan, 2016; Rodriguez & Wiengarten, 2017). Concerning the practice for efficient resource use, a firm that has the capacity to use recycled material is basically contributing to environmental protection (Cheng & Shiu, 2012; Dalhammar, 2016; Rodriguez & Wiengarten, 2017).

Strategies generating zero waste push the firm to implement process eco-innovation during production (Cheng & Shiu, 2012). The main factors that foster the adoption of the process of eco-innovation include acquisition and the use of green technologies (Frondel et al., 2008; Guziana, 2011) as they comply with environmental regulations.

However, it is still arguable whether the technology for environmental management may improve eco-innovation activities at the firm level. Process eco-innovation also involves reusing product components, which in turn minimizes the generation and disposition of waste (Y.-C. Chen, 2018; Dalhammar, 2016; Hellström, 2007).

Despite various challenges that occur during the implementation of circular economy principles, organizations are expected to improve firm's practices that lead to eco-innovation (García-Granero et al., 2018). The organization has to have eco-innovative human resources, environmental protective measures, pollution prevention objectives, and improved re-manufacturing systems (Cheng & Shiu, 2012; Iritani et al., 2015; Tseng et al., 2013). Existing eco-innovation studies also recognize the market structure that facilitates the adoption of circular economy (Triguero et al., 2013). Different indicators of market eco-innovation performance emphasize product packaging such as reusable or returnable types of packaging, improved packaging design, and lastly, the quality of products introduced to the market (Cheng & Shiu, 2012; Chiarvesio et al., 2015; Lindh et al., 2016).

This study is based on previous arguments to further describe the relationship between eco-innovation and the development of a circular economy in Rwanda. However, the measurement of eco-innovation is obtained from performance indicators of four categories of eco-innovation, namely process eco-innovation, product, organizational, and market eco-innovation. Hence, this research tests the following hypotheses:

H1a: Product eco-innovation activities performed in manufacturing firms have a positive influence on attaining circular economy principles in Rwanda.

H1: Process eco-innovation activities performed in manufacturing firms have a positive influence on attaining circular economy principles in Rwanda.

H1c: Marketing eco-innovation activities performed in manufacturing firms have a positive influence on attaining circular economy principles in Rwanda.

H1d: Organizational eco-innovation activities performed in manufacturing firms have a positive influence on attaining circular economy principles in Rwanda.

3.1.2. Green technology and eco-innovation

To achieve a sustainable transition, the inter-relation of eco-innovation and circular economy is paramount as eco-innovation is an instrumental factor in achieving circular economy (Kiefer et al., 2021). (Bossle et al. (2016) described the factors to drive eco-innovation towards improved environmental performance, including technology, regulatory & environmental managerial concern, and environmental protection capability. Eco-innovation takes advantage of technology to promote green production. J. Chen et al. (2017) state the influence of eco-innovation practices of firms on the acquisition of technology and vice versa. According to the study by J. Chen et al. (2017), these practices initiate technology-related R&D, which in turn, increase green patents and technology inventions.

On the other hand, García-Granero et al. (2018) described the indicators to measure the successful eco-innovation of firms and confirmed the importance of acquiring eco-friendly technology and green patents or inventions during the process of eco-innovation of firms. Despite the fact that Kuo & Smith, (2018) argued that with advancing technology, eco-innovation activities become much more complicated, many studies, however, demonstrated the importance of technology during eco-innovation activities. Hence, they show the importance of technology toward eco-innovation and sustainability.

For instance, the use of IoT as a fast-growing technology contributes to achieving circular economy in manufacturing companies by minimizing energy consumption during production and other processes. Therefore, for environmental impact, IoT technology is used in manufacturing design, production, and services such as assembling and disassembling the components, waste recycling, and disposal (Tao et al., 2016). Environmental sustainability performance is also due to the acquisition of new emerging technology such as artificial intelligence, big data, and cloud computing (Mat Daut et al., 2017; Nowicka, 2016; Papadopoulos et al., 2017). Environmental Management Systems integrate processes and procedures for environmental performance information within a firm and play a vital role in eco-process and eco-product innovations as it provides potential information during firm difficulties associated with reducing environmental impact (Fernando & Wah, 2017). Additionally, Rwanda has deployed technology infrastructure, including those mentioned as critical drivers of eco-innovation but it is not clear yet if the firms are taking advantage yet. Therefore, this study proposes the following hypotheses:

H2a: Manufacturing firms that acquire green technology in Rwanda increase their product eco-innovation activities.

H2b: Manufacturing firms that acquire green technology in Rwanda increase their process eco-innovation activities.

H2c: Manufacturing firms that acquire green technology in Rwanda increase their marketing eco-innovation activities.

H2d: Manufacturing firms that acquire green technology in Rwanda increase their organizational eco-innovation activities.

3.1.3. Environmental regulation and eco-innovation

Environmental regulation refers to regulations set by the government in order to protect the environment (Liao & Tsai, 2019). It is considered a key factor in developing eco-innovation culture and sustainability of firms (Doran & Ryan, 2012; Fernando & Wah, 2017). Regulations drive eco-innovation development, adoption as well as diffusion (Hojnik & Ruzzier, 2016). It gives strict guidelines to firms so that they comply with environmental requirements. Fernando & Wah (2017) argued that the stronger the environmental regulations and policies, the more firms become eco-innovative, and with policies, the manufacturing companies exercise the management of resources. Moreover, Wagner & Llerena (2011) explained that the regulations are direct drivers of eco-innovation. The environmental regulations are the most common and frequent factors that trigger successful eco-innovation (Hojnik & Ruzzier, 2016). Recent studies argued the role of regulations in the development of eco-innovation, and the findings demonstrate its driving capability to all types of eco-innovation. According to (Hojnik & Ruzzier, 2016), regulations and market pull are the most significant drivers of product eco-innovation as well as product eco-design capability, where other factors such as green technology and R&D facilitate during the implementation of such innovations. Additionally, regulation is a key factor of process eco-innovation as well as organizational eco-innovation, however, little significance of regulation can be observed to marketing eco-innovation.

Previous studies affirmed the emergence of regulations for the development of eco-innovation. However, it is unclear if the intensity of regulations equally affects firms. Liao & Tsai (2019) argued that firms with extensive innovation capabilities are more likely to comply with current environmental conditions where those using advanced technology are only capable of complying with regulation pressure enacted by the government. Yao et al. (2019) studied the impact of eco-innovation on firms ‘value moderated by environmental regulation. The findings describe the significance of regulations to improve eco-process innovation activities and the negative relationship between eco-product innovation and regulations. You et al.

(2019) analyzed the influence of environmental regulation on the eco-innovation capabilities of Chinese firms and explained that environmental regulations exhibit a significant preventive effect on a firm's eco-innovation during different development stages of China.

This study, therefore, considers environmental regulations enacted by the Rwandan government and aims to explore their influence on the eco-innovation activities of firms. According to previous theories, it is not yet clear if the regulations have a positive impact on different types of eco-innovation (eco-process, eco-product, eco-marketing, and eco-organizational innovation); therefore, the following hypotheses are tested.

H3a: Environmental regulations have a positive impact on product eco-innovation activities of manufacturing firms in Rwanda.

H3b: Environmental regulations have a positive impact on process eco-innovation activities of manufacturing firms in Rwanda.

H3c: Environmental regulations have a positive impact on marketing eco-innovation activities of manufacturing firms in Rwanda.

H3d: Environmental regulations have a positive impact on organizational eco-innovation activities of manufacturing firms in Rwanda.

3.1.4. Market demand and eco-innovation

The circular economy model introduced multiple opportunities for environmental protection, particularly by changing market demand mechanisms and product consumption patterns. Sustainable eco-innovation depends on market demand (Iritani et al., 2015). Manufacturing companies that collaborate and use feedback and information from customers about environmental concerns are likely to improve eco-innovation activities internally. With this strategy, the firms acknowledge what is required and what the customer needs from the market. Hojnik & Ruzzier (2016) describe market demand as a key driver that facilitates implementation of eco-innovation, and its importance is significant in eco-product, eco-process as well eco-organizational innovations. Meeting market and customer demands plays a crucial role and is highlighted as a motivation towards eco-innovation practices (Cai & Li, 2018). This study assumes that customer and market demand can initiate more opportunities for firms, motivating them to engage and invest in eco-innovation culture. Thus the following hypotheses are tested.

H4a: Market demand has a positive influence on product eco-innovation activities of manufacturing firms in Rwanda.

H4b: Market demand has a positive influence on process eco-innovation activities of manufacturing firms in Rwanda.

H4c: Market demand has a positive influence on marketing eco-innovation activities of manufacturing firms in Rwanda.

H4d: Market demand has a positive influence on organizational eco-

innovation activities of manufacturing firms in Rwanda.

3.1.5. Circular supply chain and circular economy

Integrating environmental concerns into organizational practices also emerges the relationship between circular economy and supply chain management. The pillars and principles of circular economy extensively explore the processes performed from extraction of raw material, manufacturing, distribution of products, use, and waste collection, where the term supply chain management derives its definition as a trajectory of goods from supplier to manufacturer toward the wholesaler and retailer to the final product consumer (Golroudbary & Zahraee, 2015). Genovese et al. (2017) confirm that for environmental sustainability, circular economy and supply chain management have a positive relationship..

Similarly, Liu et al. (2018) argue the relationship between green supply chain management and circular economy for both aim to improve environmental and economic performance, and the combination of both perspectives is called circular supply chain (Angelis et al., 2018). The circular economy initiatives also describe the use and consumption of energy to deliver products and collect waste. The use of renewable, clean, and green energy for these processes contributes to the protection of the environment. This clearly depicts the close relationship between circular economy and green supply chain management.

A closed-loop supply chain management systems optimizes the dynamics to collect and recycle waste. The complex operations and initiatives have to be considered from the product manufacturing stage. Golroudbary & Zahraee (2015) mentioned that the product life cycle process is the manufacturer's responsibility in some countries. Therefore, this study argues that keeping track of materials, products, and wastes can be a reason for firms to initiate circular economy activities to generate value from waste. Thus, the following hypothesis is tested.

H5: Circular supply chain management influences circular economy principles in manufacturing firms in Rwanda.

3.2. Methodology

To meet the objectives of this study, explanatory research is employed to investigate causal inter-relationships of model constructs divided into dependent and independent variables. Initially, a qualitative investigation was conducted by interviewing environmental, industrial, and innovation policymakers. Gaining their understanding on circular economy contributed to formulating a questionnaire and selecting appropriate respondents among the industries. The data collection and analysis is based on individual manufacturing firms across Rwanda.

The respondents are selected based on their responsibilities toward the achievement of circular economy in their respective industries. This study assumes that the more the firms understand the dynamics of circular economy, the more the principles of circular economy will be achieved.

3.2.1. Structural Equation Modelling

The structural equation modelling (SEM) is a statistical method used to analyze the complex relationships between variables (Hair et al., 2019). It is one of the advanced multivariate regression models (Jannoo et al., 2015) and has also been an essential statistical analysis method that handles interrelationships between latent (unobserved) variables (Xiong et al., 2015) in various applications. In addition to this, the structural equation modelling method allows the researchers to test the assumptions that validate the study's hypotheses. SEM is widely preferred among other statistical tools, including multivariate regression and factor analysis tools, for its ability to carry out path statistical analysis and factor analysis at the same time (Xiong et al., 2015).

Developing a path model, a diagram that displays the relationships between variables and describing all the hypotheses to test (Sarstedt et al., 2017) involves considering two different elements; the structural model and the measurement model. Respectively, they represent structural paths available among the constructs of the model and the relationships between individual constructs with its associated indicators. Hence these two elements are very important during the design of the path model (Sarstedt et al., 2017). The variables that are only independent in the model are known as exogenous variables, and those serving as dependent variables or both are named endogenous variables. The magnitude of the relationship between variables is represented by path coefficients which are also the results of regressions between two variables, namely independent and dependent. This study considers metrics associated with Partial Least Squares Structural Equation Modelling (PLS-SEM) that enable the estimation of complex models with different variables, indicators, and structural paths. Generally, SEM is applied when the study analyses a theoretical framework test, especially from an estimation, uncertainty, and prediction point of view. Also, when the model is complex with a large number of variables, when the aim is to clearly understand the theoretical perceptions of a certain study. For instance, in the case of exploratory research with limited theoretical background, and this study uses PLS-SEM due to its high statistical power (Sarstedt et al., 2017). Therefore, this study considered the following facts while reporting using partial least squares structural equation modeling (PLS-SEM).

The sample size: before data collection and analysis, it is required to consider the sample size because it is among the critical element to test the proposed model (Xiong et al., 2015). PLS-SEM generally functions well with a relatively small sample size and when the model consists of a large number of constructs (Hair et al., 2019; Sarstedt et al., 2017).

Reflective and formative measurements: This study performed assessments such as loadings, Cronbach's alpha, composite reliability, AVE, analysis for redundancy, significance of indicator, etc. These measurements are performed with robustness checks such as Confirmatory Tetrad Analysis (CTA) which enables substantiating the specification of measurement models (Sarstedt et al., 2017).

Structural model assessment: consists of analyzing explanatory power and out-of-sample predictive power, significance of path coefficients, similarly added to other recommended evaluations such as collinearity and indicator weights (Hair et al., 2019).

3.2.2. Theoretical model

Figure 3.1 Theoretical model

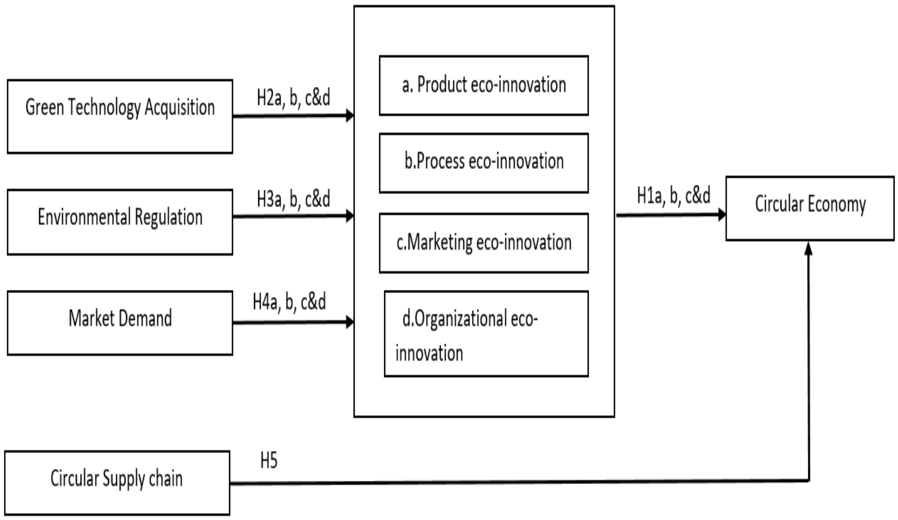

Table 3.2: Constructs and measurement items

Model construct	Measurement Item	Abbreviation	References
Green Technology Acquisition (GTA)	This Firm/Industry has the necessary technology to design eco-friendly products?	**GTA1**	(Cai & Li, 2018)
	This Firm/Industry has some successful eco-innovation experience?	**GTA2**	

	The employees of this Firm/Industry have high product design capabilities?	**GTA3**	
Environmental Regulation (ENR)	Environmental regulation is enforced without tolerance?	**ENR1**	(Agan et al., 2013)
	This Firm/Industry finds environmental laws comprehensive?	**ENR2**	
	Environmental regulation helps this Firm/Industry to be eco-innovative?	**ENR3**	
Market Demand (MTD)	The customers of this Firm/Industry have a clear demand regarding environmental issues?	**MTD1**	(Agan et al., 2013)
	The major customers of this Firm/Industry give environmental feedback about the products?	**MTD2**	

	Customer demands motive this Firm/Industry in environmental effort?	**MTD3**	
Circular Supply Chain Management (SCM)	This Firm/Industry tracks products using environmental management system always?	**SCM1**	(Zhu et al., 2008)
	This Firm/Industry keeps in contact with suppliers for environmental objectives?	**SCM2**	
	The management team of this Firm/Industry are committed to green supply chain management?	**SCM3**	
	Does this firm reuse recycled materials to manufacture new products?	**PTE1**	

Eco-Innovation	**Product**	Does this firm consider product life cycle in order to reduce waste and other environmental impact?	**PTE2**	(García-Granero et al., 2018)
		Do you agree that it is easy to recycle the products this Firm/Industry manufactures?	**PTE3**	
	Process	Do you agree that this Firm/Industry keeps wastes to minimum?	**PCE1**	
		Does this Firm/Industry always use renewable energy? e. g: solar panels?	**PCE2**	
		Does this Firm/Industry have a waste recycling facility?	**PCE3**	
		Does Firm/Industry have environmental pollution prevention plan?	**OEI1**	

Organizational	Does this Firm/Industry rewards people who have contributed to environmental protection?	**OEI2**	
	This Firm/Industry invests in environmental research?	**OEI3**	
Marketing	This Firm/Industry manufactures and promotes eco-friendly products?	**MEI1**	
	All products of this Firm/Industry have quality certification?	**MEI2**	
Circular economy (CEC)	This Firm/Industry reduces input and use of natural resources?	**CEC1**	(Elia et al., 2017)
	This Firm/Industry increases durability of products?	**CEC2**	
	This Firm/Industry separate wastes by types and disposes them?	**CEC3**	

3.2.3. Data collection

The online questionnaire was forwarded to 341 manufacturing companies across the country divided into 7 different firm categories: those that manufacture plastic related products; ceramics; steel, textiles; wood & furniture; electrical & electronics; and lastly, food & beverage industries. The questionnaire consists of 26 items excluding demographic related questions whereby three items represented acquisition of green technology, environmental regulation, market demand, circular supply chain management, circular economy constructs. Eleven items represented eco-innovation construct divided into four different categories: product eco-innovation, process eco-innovation, marketing eco-innovation, and organizational eco-innovation. The survey participants are 275, and this study does not consider 17 incomplete answers; hence the number of valid responses is 258.

Chapter 4. Result analysis

4.1. Data demographic analysis

The categories of firms that exploit wood, textiles, and ceramics occupy the highest percentage (21.70%, 21.70%, and 18.21%) of total respondents, respectively. The categories of plastic and food & beverage occupy 17.05% and 12.40%, respectively. Less represented categories are steel and electrical & electronic with 7.75% and 1.16%, respectively. Further details are described in Table 4.1.

Table 4.1: Data demography

Firm Category	Percentage	Location (Province)	Observations
Plastic	17.05%	East	3
		Kigali	30
		North	2
		South	5
		West	4
Steel	7.75%	East	2
		Kigali	13
		North	3
		South	1
		West	1

Textile	21.70%	East	5
		Kigali	32
		North	5
		South	8
		West	6
Wood & furniture	21.70%	East	12
		Kigali	25
		North	3
		South	5
		West	11
Electrical & electronic	1.16%	East	0
		Kigali	3
		North	0
		South	0
		West	0
Food & beverage	12.40%	East	5
		Kigali	13
		North	6
		South	5
		West	3
Ceramic	18.21%	East	3
		Kigali	19
		North	9
		South	3
		West	3
Total	100%		258

4.2. Measurement of model variables

Multi-item scale is used to measure each of the constructs in the model, and a 5-point Likert-type scale ranged from strongly disagree=1 to strongly agree=5. Eleven items measured eco-innovation construct which consist of Process eco-innovation, Product eco-innovation, Marketing eco-innovation, and Organizational eco-innovation items. Three items measured each of the remaining constructs: circular economy, green technology acquisition, market demand, environmental regulation, and circular supply chain management. The indicators used were adopted from different studies, as shown in Table 3.2.

4.3. Descriptive statistics

Table 4.2: Indicators descriptive statistics

Item	Minimum	Maximum	Mean	Std. Deviation
GTA1	1	5	2.44	0.978
GTA2	1	5	2.46	0.891
GTA3	1	5	2.53	0.900
ENR1	1	5	2.42	1.124
ENR2	1	5	2.33	1.092
ENR3	1	4	2.43	1.031
MTD1	1	5	3.71	0.601
MTD2	1	5	3.70	0.642
MTD3	1	5	3.74	0.636
SCM1	1	5	3.52	0.979
SCM2	1	5	3.46	0.986
SCM3	1	5	3.38	0.948
PTE1	1	5	2.97	0.910
PTE2	1	5	3.03	0.877
PTE3	1	5	3.56	0.920
PCE1	1	5	2.90	1.034
PCE2	1	5	2.88	1.081
PCE3	1	5	2.86	0.980
OEI1	1	5	2.83	0.971
OEI2	1	5	2.91	0.866
OEI3	1	5	3.03	0.871
MEI1	1	5	3.08	0.953
MEI2	1	5	3.01	0.848
CEC1	1	5	3.22	0.769
CEC2	1	5	3.19	0.855
CEC3	1	5	3.22	0.862

Table 4.3: Construct descriptive statistics

	Min.	Max.	Mean	Std. Dev.	Skewness	Kurtosis
CE	1.00	5.00	3.210	0.713	-0.661	0.979
CSCM	1.00	5.00	3.454	0.852	-0.301	0.444
ENR	1.00	4.33	2.390	0.952	0.208	-1.020
GTA	1.00	5.00	2.478	0.777	0.591	-0.210
MEI	1.00	5.00	3.046	0.826	-0.228	-0.313
MTD	1.00	5.00	3.717	0.502	-1.198	4.548
OEI	1.00	5.00	2.922	0.765	0.057	-0.392
PCE	1.00	5.00	2.882	0.932	0.266	-0.630
PTE	1.00	5.00	3.187	0.716	-0.728	1.351

This study considers individual measured items to observe how different categories of eco-innovation activities are performed in manufacturing firms, and the result shows that the means of PTE2, PTE3, OEI3, MEI1, and MEI2 are comparatively higher than other items in eco-innovation construct with a mean and standard deviation of 3.03 (SD=0.877), 3.56 (SD=0.920), 3.03 (SD=0.871), 3.08 (SD=0.953) and 3.01 (SD=0.848), respectively. This shows that the firms consider eco-innovation practices as one step ahead to achieve the principle of circular economy since they affirm that their products can be easily recycled. Additionally, firms are willing to consider the quality and promote eco-friendly products as a component of marketing eco-innovation.

Overall, descriptive statistics of the circular economy show a mean of 3.21 (SD=0.713) which shows an average positive perception of a circular economy paradigm shift among manufacturing firms in the country. Similarly, the descriptive statistics of MEI shows a mean of 3.046 (SD=0.826), OIE with a mean 2.922 (SD=0.765), PCE with a mean 2.883 (SD=0.932), and PTE with a mean 3.187 (SD=0.716), which shows that the industries perform average activities related to eco-innovation. On the other hand, the acquisition of green technology and comprehensive environmental regulations are still problematic, hence the mean of 2.47(SD=0.777) and 2.40(SD=0.952).

Skewness and Kurtosis

Skewness is a measure of symmetry or otherwise a lack of symmetry. It describes the degree of distortion from the normal distribution curve. Skewness measure ranges between -1 and +1(Groeneveld & Meeden, 1984). Similarly, Kurtosis measures the peak and tail relative to the normal distribution. If it ranges between -10 and +10 (*Laboratory Statistics*, 2018), it is considered acceptable to prove normal univariate distribution. The descriptive statistics show that the constructs measured are symmetric except market demand which presents an out of range value of -1.198. The individual construct skewness range between -1.198 and + 0.591, and the Kurtosis ranges from -1.020 and 4.548, which shows that the distribution of each construct is normally univariate.

4.4. Reflective measurement model analysis

The measurement model is carried out using smartPLS (v.3.3.3) software. The reflective measurement model assesses indicator loadings, internal consistency reliability, convergent validity, and discriminant validity.

4.4.1. Indicator loadings

Figure 4.4: Indicator loadings

Indicators	Loading value	Indicators	Loading value
CEC1	0.844	**MTD3**	0.793
CEC2	0.861	**OEI1**	0.812
CEC3	0.877	**OEI2**	0.831
ENR1	0.872	**OEI3**	0.9
ENR2	0.883	**PCE1**	0.902
ENR3	0.885	**PCE2**	0.907
GTA1	0.844	**PCE3**	0.901
GTA2	0.857	**PTE1**	0.866
GTA3	0.826	**PTE2**	0.835
MEI1	0.912	**PTE3**	0.655
MEI2	0.923	**SCM1**	0.811
MTD1	0.744	**SCM2**	0.94
MTD2	0.859	**SCM3**	0.866

The diagram above shows the loadings of measured indicators, (Hair et al., 2019) recommend those that indicate at least 50% of item's variance. Therefore, the reliability of items is assured by a loading value above 0.708. This study considers all items except PTE3, which has a low loading value of 0.655.

4.4.2. Internal consistency reliability

Internal consistency is a measurement between items based on their correlations. This study uses composite reliability and Cronbach'Alfa values as good measures of internal consistency reliability (Ringle & Sarstedt, 2016). According to Hair et al. (2019) and Bagozzi & Yi (1988), an acceptable minimum value of Cronbach'Alpha is 0.7, and that of composite reliability should be in the range of 0.6 and 0.95. Above this range shows data redundancy, and it is not desirable to measure reliability. In this study, the PTE construct has the minimum internal consistency reliability with 0.700 (Cronbach's Alpha) and the PCE construct shows the highest internal consistency reliability value of 0.888 (Cronbach's Alpha). Previous studies show that internal consistency reliability cannot be measured only by Cronbach's Alpha value since it is a less precise measure of reliability. Therefore, this study also considers composite reliability test which ranges between 0.842 and 0.93 as shown in Table 4.4.

Table 4.5: Internal consistency reliability values

Construct	Cronbach's Alpha	Composite Reliability	Average Variance Extracted (AVE)
CE	0.826	0.896	0.741
CSCM	0.85	0.906	0.764
ENR	0.854	0.912	0.774
GTA	0.796	0.88	0.71
MEI	0.811	0.914	0.841
MTD	0.721	0.842	0.64
OEI	0.806	0.885	0.72
PCE	0.888	0.93	0.816
PTE	0.700	0.866	0.763

4.4.3. Convergent validity

Assessment of the reflective model includes the test of convergent validity of used constructs. It refers to the extent to which a measured item converges to explain the variance of its items (Hair et al., 2019). The convergent validity is measured by Average Variance Extracted

(AVE), and is obtained from the average mean value of squared loadings of each construct. The minimum threshold value of AVE is 0.5 (Hair et al., 2019), (Bagozzi & Yi, 1988). The average variance extracted values for this study fall above the minimum value accepted as shown in Table 4.4, ranging from 0.640 to 0.841 for market demand and marketing eco-innovation constructs, respectively.

4.4.4. Discriminant validity

Discriminant validity measures the extent to which one construct empirically differs from all other constructs in a measured model. This study uses the Fornell-Larcker criterion and the Heterotrait-Monotrait Ratio (HTMT). The discriminant validity of a particular construct using the Fornell-Larcker criterion is calculated by comparing the square root of its average variance extracted with the correlation coefficients of the remaining constructs with the condition that the calculated square root of AVE should be higher than the intercorrelation values.

Table 4.6: Fornell-Larcker criterion matrix

	1	2	3	4	5	6	7	8	9
1.CE	0.861								
2.CSCM	-0.074	0.874							
3.ENR	0.135	0.121	0.88						
4.GTA	0.151	0.075	0.282	0.843					
5.MEI	0.051	0.19	0.554	0.09	0.917				
6.MTD	0.062	0.158	0.354	-0.134	0.288	0.8			
7.OEI	0.063	0.279	0.505	0.226	0.763	0.217	0.849		
8.PCE	0.139	0.214	0.574	0.327	0.584	0.2	0.664	0.903	
9.PTE	0.019	0.354	0.503	0.16	0.657	0.164	0.625	0.643	0.874

Heterotrait-Monotrait Ratio (HTMT)

The Heterotrait-Monotrait Ratio is a mean value of item correlations of different constructs relative to the mean average correlation of items that measure that construct (Hair et al., 2019). It is recommended that the HTMT value should not exceed 0.9. Therefore, Table 4.5 and 4.6 show evidence of the existence of discriminant validity.

Table 4.7: Heterotrait-Monotrait Ratio matrix

	1	2	3	4	5	6	7	8
1.CE								
2.CSCM	0.086							
3.ENR	0.161	0.145						
4.GTA	0.193	0.106	0.345					
5.MEI	0.063	0.233	0.666	0.117				
6.MTD	0.084	0.191	0.447	0.172	0.366			
7.OEI	0.097	0.356	0.602	0.275	0.936	0.265		
8.PCE	0.162	0.251	0.654	0.383	0.688	0.237	0.782	
9.PTE	0.082	0.45	0.654	0.209	0.884	0.22	0.832	0.823

4.5. Structural model analysis

4.5.1. Collinearity test

This study assesses formative measures based on convergent validity, collinearity, statistical significance, and indicator weights (Hair et al., 2019). Convergence validity is calculated by the average variance extracted, as shown in Table 4.4. The collinearity, however, is evaluated by the Variance Inflation Factor (VIF). The value above 5 indicates collinearity issues among constructs and the minimum value of VIF is 1.

The table 4.7 describes the VIF values of construct used to measure circular economy in the model.

Table 4.8: Collinearity test values

Relationship	VIF
CSCM>CE	1.176
MEI>CE	2.799
OEI>CE	2.994
PCE>CE	2.12
PTE>CE	2.34

4.5.2. Determination coefficients

This study uses the coefficient of determination R^2 to indicate the extent to which the variation in response is explained by the model (Akossou & R., 2013). (Marcoulides, 1998) proposes interpreting R^2 ≥0.70, ≥0.20, and ≥0.10 as substantial, moderate, and weak. Table 4.9 describes R^2 values for all dependent variables in the model, and the values indicate a moderate fit to explain variances in dependent variables.

Table 4.9: Coefficients of determination

Constructs	R^2
CE	0.34
MEI	0.31
OEI	0.33
PCE	0.36
PTE	0.32

4.5.3. Weights of indicators

The non-parametric characteristics of PLS-SEM allow this study to evaluate the weight of each indicator used to measure the constructs by performing bootstrapping technique. The findings show four non-significant indicators.

Table 4.10: Non-significant indicators weights

Indicator	**CEC1**	**SCM1**	**SCM2**	**SCM3**
T-Statistic	1.804	0.498	0.063	0.238

Statistically non-significant indicators are supposed to be removed for further study. However, researchers suggest considering their absolute contribution to the model unless they also have a non-significant loading value, where it is then recommended to remove them from the model (Latan & Ramli, 2013) ,(Hair et al., 2019). This study, therefore, keeps all the indicators for further analysis. Table 4.9 shows all indicator weights.

Table 4.11: Indicator weights

Indicators	T Statistics (|O/STDEV|)	P Values
CEC1 <- CE	3.773	0
CEC2 <- CE	2.121	0.034
CEC3 <- CE	1.804	0.072
ENR1 <- ENR	17.625	0
ENR2 <- ENR	18.572	0
ENR3 <- ENR	17.113	0
GTA1 <- GTA	5.078	0
GTA2 <- GTA	5.106	0
GTA3 <- GTA	4.552	0
MEI1 <- MEI	19.686	0
MEI2 <- MEI	23.352	0
MTD1 <- MTD	3.61	0
MTD2 <- MTD	5.744	0
MTD3 <- MTD	3.174	0.002
OEI1 <- OEI	10.858	0
OEI2 <- OEI	10.941	0
OEI3 <- OEI	13.121	0
PCE1 <- PCE	23.764	0
PCE2 <- PCE	21.035	0
PCE3 <- PCE	22.462	0
PTE1 <- PTE	10.568	0
PTE2 <- PTE	11.018	0
PTE3 <- PTE	5.297	0
SCM1 <- CSCM	0.679	0.498
SCM2 <- CSCM	1.866	0.063
SCM3 <- CSCM	1.182	0.238

4.5.4. Correlations

Table 4.12: Correlation table

	Mean	Std. Dev.	1	2	3	4	5	6	7	8	9
1.CE	3.210	0.713	1								
2.CSCM	3.454	0.852	-0.071	1							
3.ENR	2.390	0.952	.136*	0.112	1						
4.GTA	2.478	0.777	.155*	0.086	.284**	1					
5.MEI	3.046	0.826	0.054	.195**	.555**	0.091	1				
6.MTD	3.717	0.502	0.058	.150*	.351**	-.130*	.277**	1			
7.OEI	2.922	0.765	0.054	.293**	.499**	.224**	.752**	.199**	1		
8.PCE	2.882	0.932	.140*	.219**	.568**	.323**	.586**	.188**	.663**	1	
9.PTE	3.001	0.780	0.017	.346**	.502**	.154*	.660**	.155*	.615**	.644**	1

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

The person correlation is computed to analyze the relationships between constructs in the model. The result shows the negative relationship (r=-.071) between the circular supply chain activities of manufacturing firms and activities related to the achievement of circular economy principles. On the other hand, there is a positive relationship between eco-innovation activities and circular economy (r=.054, .054, .140*, .017) for MEI, OEI, PCE and PTE respectively. Additionally, there is a strong positive relationship between environmental regulation, green technology acquisition, market demand, and different types of eco-innovation activities of manufacturing firms, as shown in Table 4.

4.5.5. Path analysis

To test the hypothesis of this study, Structural Equation Modelling (SEM) was applied and the results obtained from the structural model and measurement model help to analyze the path coefficients, t-statistics value, as well as significance level between latent constructs.

Table 4.13: Path analysis coefficients

Hypotheses	Relationship	Std. Error	Std.coeff. Beta	t	Sig.	Decision
H1a	PTE>CE	0.086	-0.099	-1.048	0.296	Not supported
H1b	PCE>CE	0.069	0.228	2.519	0.012	Supported
H1c	MEI>CE	0.088	0.025	0.246	0.806	Not supported
H1d	OEI>CE	0.098	-0.031	-0.298	0.766	Not supported
H2a	GTA>PTE	0.059	0.007	0.127	0.899	Not supported
H2b	GTA>PCE	0.065	0.185	3.387	0.001	Supported
H2c	GTA>MEI	0.059	-0.052	-0.922	0.357	Not supported
H2d	GTA>OEI	0.057	0.103	1.765	0.079	Not supported
H3a	ENR>PTE	0.051	0.508	8.194	0	Supported
H3b	ENR>PCE	0.057	0.503	8.712	0	Supported
H3c	ENR>MEI	0.051	0.541	9.135	0	Supported
H3d	ENR>OEI	0.05	0.451	7.299	0	Supported
H4a	MTD>PTE	0.093	-0.023	-0.376	0.707	Not supported
H4b	MTD>PCE	0.104	0.035	0.629	0.53	Not supported
H4c	MTD>MEI	0.094	0.08	1.396	0.164	Not supported
H4d	MTD>OEI	0.091	0.054	0.902	0.368	Not supported
H5	CSCM>CE	0.056	-0.082	-1.226	0.221	Not supported

Table 4.11 indicates in detail that activities related to circular supply chain management, product eco-innovation, and organizational eco-innovation have negative influences on the circular economy of

manufacturing firms in Rwanda with (β=-*.082, p=.221, t=-1.226*), (β=-*.099, p=.296, t=-1.048*) and (β=-*.031, p=.766, t=-.298*) for CSCM, PTE, and OEI respectively. On the other hand, PCE and MEI have positive influences on CE with β=.228 and .025, respectively. This study also observes a positive influence of green technology and environmental regulation on activities related to product eco-innovation among manufacturing firms in Rwanda with (β=*.007, p=.899, t=.127*) and (β=*.508, p=.000, t=8.194*) for GTA and ENR, respectively. However, this study finds negative influence of market demand on product eco-innovation activities of firms in Rwanda with (β=-*.0238, p=.707, t=-.376*). Acquisition of green technology, environmental regulation, and market demand show a positive influence on process eco-innovation practices of the firms in Rwanda with (β=*.185, p=.001, t=3.387*), (β=*.503, p=.000, t=8.712*) and (β=*.035, p=.053, t=.629*), respectively. Also environmental regulation and market demand have a positive influence on marketing eco-innovation practices of firms with (β=*.541, p=.000, t=9.135*) and (β=*.08, p=.164, t=1.396*), respectively. On the other hand, acquisition of green technology has a negative impact on marketing eco-innovation of manufacturing firms in Rwanda with (β=*-.052, p=.357, t=-.922*). Also, acquisition of green technology, environmental regulation, and market demand have a positive influence on organizational eco-innovation activities of firms in Rwanda with (β=*.103, p=.079, t=1.765*), (β=*.451, p=.000, t=7.299*), and (β=*.054, p=.368, t=0.902*), respectively.

4.6. Discussion of results and implication

Discussion

This study explores the factors influencing the sustainable development of circular economy among manufacturing firms in Rwanda, essentially eco-innovation activities and circular supply chain management.

The results show that eco-innovation activities do not fully influence circular economy in manufacturing firms. Product manufacturing processes help firms keep waste to a minimum by effectively sorting and using waste recycling facilities. To achieve circular economy paradigm principles, there is a necessity of the firms to reduce the generation of wastes, as well as generating facilities to separate and dispose of the wastes. Therefore, this study affirms a positive influence of process eco-innovation activities in achieving circular economy principles in manufacturing firms in Rwanda. Hence, hypothesis H1b is supported. On the other hand, firms do not consider product lifecycle that help to reduce waste with other environmental negative impacts and the reuse of recycled materials to make new products. This finding explains that the firms contribute less to material recovery, which in turn, impacts the manufacturing of new products with improved characteristics. Therefore, this study shows a negative influence of product eco-innovation activities of firms on circular economy in Rwanda, hence hypothesis H1a is not supported. Promoting the use of eco-friendly products is necessary for practices of marketing eco-innovation. Furthermore, this study observed the lack of improved product delivery capability of firms; hence the marketing eco-innovation activities of firms do not show a positive influence on circular economy in Rwanda. Therefore, hypothesis H1c is not supported.

The findings show that firms do not have environmental pollution prevention plans as one component to evaluate the organizational eco-innovation capability of a firm. Additionally, there is a lack of managerial commitment toward circular economy. This study, therefore, states that organizational eco-innovation practices among manufacturing firms in Rwanda do not have a positive influence on circular economy; hence hypothesis H1d is not supported. The above-tested hypotheses responds to the first research question to investigate if eco-innovation activities of manufacturing firms have an impact on achieving a circular economy in Rwanda. This study shows that except process eco-innovation activities, other eco-innovation practices do not have a significant impact on achieving a circular economy in Rwanda.

This study assumes that product eco-innovation, which focuses on product lifecycle, is achieved by the use of clean technology during manufacturing, high product design capability, the motivation from eco-friendly product customers, and comprehensive environmental regulations. This research observed a lack of green technology acquisition where the firms lack designing capability added to a lack of customer engagement to attain circular economy principles. Hence, market demand and acquisition of green technology do not positively influence the circular economy in Rwanda. Therefore, hypotheses H2a and H4a are not supported by the results of this study. Despite the lack of green technology and market demand, product eco-innovation is influenced by available environmental regulations, which help firms be eco-innovative by minimizing their negative environmental impact. Therefore, this study states that environmental regulation has a positive impact on product eco-innovation in manufacturing firms in Rwanda; hence hypothesis H3a is supported. Similarly, the process of eco-innovation is positively influenced by environmental regulation especially to enforce firms that have product recycling facilities and minimizing the waste in general. It is negatively influenced by green technology and market demand. Therefore, this study supports hypothesis H3b and rejects H2b and H4b.

Offering different technological and environmental solutions to existing products is due to the performance of marketing eco-innovation of firms. This study finds that green technology and market demand do not have a positive influence on marketing eco-innovation of firms but a positive influence from environmental regulation supporting H3c. Hence the hypotheses H2c and H4c are not supported due to lack of product promotion, and lack a of product quality and design capability.

This study also investigates managerial commitment and methods that improve the achievement of circular economy principles, and the results show that environmental regulations significantly influence organizational eco-innovation of firms in Rwanda; hence hypothesis H3d is supported. Furthermore, it shows that green technology and market demand do not have a positive influence on practices and implementation that lead to eco-innovation. Therefore, this study does not support hypotheses H2d and H4d.

The second research question of this study is investigated by analyzing influential mechanisms of circular supply chain management to attain circular economy principles in manufacturing firms in Rwanda. It is shown that there is a lack of tracking products and materials from firms to consumers where firms do not keep in contact with suppliers and wholesalers to ensure better environmentally friendly product quality. The result of this study shows that activities related to the circular supply chain do not have a positive influence on circular economy in Rwanda hence hypothesis H5 is not supported.

Implications

Empirical results of this study contribute to the literature on the development of circular economy in manufacturing firms, especially in Rwanda. It gives decision-makers and top managers of firms the actual status and evaluation of eco-innovation, circular supply chain activities, and their influences to achieve circular economy. Therefore, this study shows that the country is at the first stage to adopt a circular economy where green technology, engagement of citizens, and many eco-innovation practices are not enough. Therefore, the government is urged to raise awareness among citizens as a practice of marketing eco-innovation to adopt eco-friendly products. Moreover, even though firms appreciate the regulation regarding clean manufacturing, there is a need to invest more in industrial research to improve product design capability. Additionally, less influence of organizational eco-innovation on circular economy implies that firms do not have environmental pollution prevention plans. This study, therefore, suggests to firm managers to make clear plans that help attain circular economy principles in manufacturing firms.

4.7. Limitation and future research

There are several limitations to consider in this study. First, the data used is collected through an online survey that has advantages such as saving time and its ability to reach target respondents easily, but the disadvantages are also numerous, such as less accuracy on some responses (Wright, 2005). Second, this study measured the eco-innovation capability of firms by subjective indicators; hence it is desirable to expand this study by evaluating key constructs using objective items.

The data used for analysis in this study was collected from owners of manufacturing firms (private sector) in Rwanda, which excludes the opinions from public companies. Therefore, to improve the validity of this study, a future study should focus on both points of view.

Chapter 5 Conclusion

This study contributes to existing theories for the sustainable development of circular economy in manufacturing firms in Rwanda. The model developed improves the understanding of circular economy dynamics and their influencing factors. The finding shows a non-significant influence of eco-innovation and circular supply chain activities on the development of circular economy principles in Rwanda. Moreover, green technology acquisition and market demand do not influence a firm’s activities related to eco-innovation. On the other hand, this study agrees that the country has enacted regulations that can influence the manufacturing of eco-friendly products.

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Appendix 1

English questionnaire

Survey on development of Circular Economy in Rwanda.

Greetings,

My name is Kundimana Antoine M. Zacharie, a graduate student in Technology Management and Economics Policy at Seoul National University-Korea.

The purpose of this study is to examine the influence of eco-innovation and green supply chain management capability of firms and industries on the development of circular economy in Rwanda.

The survey requires 2-4 minutes. The information collected will be used only for this study and we guarantee you absolute anonymity. For any queries, please contact me at: antoine121292@gmail.com

Definition:

Circular economy: economic system that enable industries to re-make products from the wastes (Food, plastic, wood, steel...).

Eco-innovation: Innovation that leads to protection of environment.

Sincerely,

Antoine M. Zacharie Kundimana

Section 1

Kindly answer the following general questions.

1. Respondent Gender

- Male
- Female

2. Respondent age

- 18-24
- 25-34
- 35-44
- 45-54
- 55-64
- 65 and above

3. Respondent highest level of education

- Primary school
- Secondary education
- Bachelor degree
- Master degree
- Doctorate or higher

4. Respondent Position

- Executive

- Director
- Manager
- Senior Staff
- Staff
- Other

The following series of questions will help this study to analyze the demography and characteristics of the industry

5. This Firm/Industry is located in which Province?
    - East
    - North
    - South
    - West
    - Kigali
6. What category this Firm/Industry belongs to?
    - Food and beverage
    - Electrical and electronic
    - Steel
    - Textile
    - Ceramic
    - Wood and furniture

- Plastic

7. Estimate the number of employees of this firm/industry.
   - 0 to 19
   - 20 to 99
   - 100 to 499
   - More than 499

Section 2

The following series of questions will help this study to analyze green technology acquisition, environmental regulation, market demand, supply chain management and eco-innovation capability of this firm/industry. Kindly choose the appropriate answer.

1- Strongly disagree
2- Disagree
3- Neutral
4- Agree
5- Strongly agree

8.This Firm/Industry has necessary technology to design eco-friendly products?	1	2	3	4	5
9.This Firm/Industry has some successful eco-innovation experience?					
10.The employees of this Firm/Industry have high product design capabilities?					
11.Environmental regulation is enforced without tolerance?					
12.This Firm/Industry finds environmental laws comprehensive?					

13.Environmental regulation helps this Firm/Industry to be eco-innovative?					
14.The customers of this Firm/Industry have a clear demand regarding environmental issues?					
15.The major customers of this Firm/Industry give environmental feedback about the products?					
16.Customer demands motive this Firm/Industry in environmental effort?					
17.This Firm/Industry tracks products using environmental management system always?					
18.This Firm/Industry keeps in contact with suppliers for environmental objectives?					
19.The management team of this Firm/Industry are committed to green supply chain management?					
20.Does this firm reuse recycled materials to manufacture new products?					
21.Does this firm consider product life cycle in order to reduce waste and other environmental impact?					
22.Do you agree that it is easy to recycle the products this Firm/Industry manufactures?					
23.Do you agree that this Firm/Industry keeps wastes to minimum?					
24Does this Firm/Industry always use renewable energy? e. g: solar panels?					
25.Does this Firm/Industry have a waste recycling facility?					
26.Does this Firm/Industry have environmental pollution prevention plan?					
27.Does this Firm/Industry rewards people who have contributed to environmental protection?					

28.This Firm/Industry invests in environmental research?					
29.This Firm/Industry manufactures and promotes eco-friendly products?					
30.All products of this Firm/Industry have quality certification?					
31.This Firm/Industry reduces input and use of natural resources?					
32.This Firm/Industry increases durability of products?					
33.This Firm/Industry separate wastes by types and disposes them?					

초 록

최근의 순환 경제의 발전은 천연 자원의 부족이 증가함에 따라 그것의 중요성과 지속가능성과의 관계를 보여주었습니다. 르완다는 다른 개발도상국 중에서도 급속한 도시화와 산업화에 직면해 있으며, 이는 음식물쓰레기, 종이쓰레기, 금속, 유리쓰레기, 전자쓰레기 등 다양한 폐기물의 발생과 밀접한 관계를 맺고 있습니다. 본 연구는 제품의 수명 주기가 끝날 때 제품이 노출되도록 설계하는 기존 산업 비즈니스 모델인 선형 비즈니스 모델에 의해 부적절한 폐기물 관리가 선호된다는 데 동의합니다.

폐기물 생성과 관련된 문제를 극복하기 위해서는 선형 비즈니스 모델에서 원형 비즈니스 모델로 전환하는 것이 무엇보다 중요합니다. 따라서 본 연구는 환경 혁신과 녹색 공급망 관리라는 두 가지 서로 다른 영향력 있는 요소와 함께 순환 경제라고 불리는 재료 흐름의 폐쇄 루프 개발에 대해 논의합니다.

이 연구는 부분 최소 제곱 구조 방정식 모델링을 사용하여

구조물과 결과 사이의 관계를 분석합니다. 국가 전체의 산업 활동이 산업 기술 능력의 부족, 제품 환경 혁신, 마케팅 및 조직의 불충분한 관행으로 인해 재료의 순환성과 정렬되지 않음을 보여줍니다 원형 경제 원칙을 달성하기 위한 주요 장벽 중 하나로써, 제품 및 재료 흐름을 추적하기 위한 불충분한 활동 및 시장 수요의 부족이 있습니다. 한편, 제조 업체의 프로세스 환경 혁신 관행과 환경 규제는 각각 순환 경제와 환경 혁신 활동에 긍정적인 영향을 미칩니다.

따라서 본 연구는 산업 선형에서 순환 비즈니스 모델로 패러다임이 전환될 필요성을 완전히 이해하기 위해 르완다 정부, 정책 입안자 및 기타 환경 보호 이해 당사자들에게 즉각적인 조치를 취하고 전국의 제조 회사들에게 인식을 제고할 것을 권장합니다.

주요어: 환경 혁신, 순환 경제, 순환 공급망 관리, 지속 가능성입니다.

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