Pakistan Journal of Commerce and Social Sciences
2020, Vol. 14 (4), 866-912
Pak J Commer Soc Sci

Renewable Energy, Circular Economy Indicators and Environmental Quality: A Global Evidence of 131 Countries with Heterogeneous Income Groups

Muhammad Tariq Majeed (Corresponding author)
School of Economics, Quaid-i-Azam University, Islamabad, Pakistan
Email: tariq@qau.edu.pk

Tania Luni
School of Economics, Quaid-i-Azam University, Islamabad, Pakistan
Email: tania_luni@yahoo.com

Article History

Received: 07 Sept 2020 Revised: 25 Nov 2020 Accepted: 10 Dec 2020 Published: 31 Dec 2020

Abstract

Increasing global warming, degrading environmental quality, and waste ending in landfills have become threats to the sustainability of ecosystems. The circular economy (CE) offers an alternative approach to the linear economy, which lowers pressure on the ecosystem. Renewable energy, as an important pillar of CE, neither generates waste nor increases the extraction of limited resources. This study explores the dynamic links of renewable energy and CE with environmental quality. This study explains the important mechanisms of circular business models in the context of contingency theory, transaction cost theory, resource-based theory, networks-based theory, and agency theory. The empirical analysis is based on a global panel of 131 countries, including a disaggregated analysis for different groups of countries according to their income levels and European Union member countries. The 2nd generation tests namely "cross sectionally augmented IPS (CIPS), cross sectionally augmented Dickey Fuller test (CADF) and Westerlund cointegration test" are applied to test the relationships between the variables. We employ novel indicators of CE such as biowaste recycling, municipal waste recycling, e-waste recycling, packaging waste recycling, trade-in recyclables, and patents in recycling to examine their impacts on environmental quality. The results suggest that renewable energy and different measures of CE significantly improve environmental quality. Energy intensity, economic growth, and urbanization degrade the environment. The study suggests that CE measures need to be promoted to combat climate change.

Keywords: biowaste recycling, CO_2 emissions, municipal waste recycling, packaging waste recycling, renewable energy consumption.

1. Introduction

Sustainable development goals were proposed to improve human life and environmental quality in such a way that the limited resources of the planet should be harnessed without compromising their quality and availability for future generations. However, since the dawn of civilization, resources are extracted to fulfill the increasing demands of human civilization without considering the fact that the regenerating capacity of any system is limited. A disproportionate resource extraction to the resource regenerative capacity leads to deterioration and depletion of natural resources. Natural resources have been accumulated over thousands of centuries; however, their amplifying use has caused extinction within a century. A linear economy exploits virgin resources. The global extraction and use of virgin materials exceeded 100 billion tons per year since 2017. Furthermore, an estimate by the international resource panel (IRP) suggests that this unsustainable use will reach to 184 billion tons by 2050, exacerbating environmental risks (Schroder, 2020).

A linear economy represents a traditional economy that is based on the extraction and use of natural resources to produce goods and services. During this production, process externalities are generated in the form of waste and pollution, which deteriorate environmental quality (see Figure 1). The waste generation hurts the environment through a reduction in availability and quality of natural capital attributable to extraction and increased pollution (Murray et al., 2017). The industrial revolution led to global growth and accelerated resource extraction and resulted in higher consumer demand, which negatively affected the circularity, and the system has stuck in the take-make-dispose system (Circle Economy, 2020).

Figure 1: Linear Economy

Climate is changing due to higher anthropogenic influence and resulting in higher frequency and intensity of extreme weather events, hurricanes and floods, droughts, higher sea levels, all this damages infrastructure, livelihood, resources, and impact health (UN DESA, 2020; Majeed and Maria, 2019a) and ecosystem. Therefore, changing climate, degrading environmental quality, decreasing finite resources, and increasing waste, all have led to the consideration of the process that enhances the generative capacity of the planet which in turn improves environmental quality and supports life on earth. It has been emphasized in the literature that "extraction of virgin and finite resources leads to a decrease in the regenerative capacity of the earth" (Bonciu, 2014). Therefore, the concept of the linear economy "produce-consume-waste" is extractive and no longer deemed of and an effort is being made to promote circular economy (CE), which eliminates the concept of waste. A CE represents "an industrial system that is restorative or regenerative by intention and design" (see Figure 2).

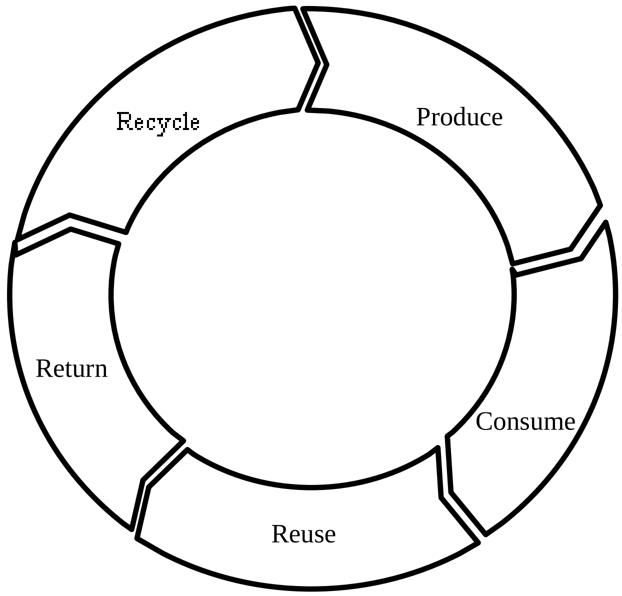

Figure 2: Circular Economy

The concept of CE emphasizes on minimization of externalities (generation of waste and pollution) and decreased use of finite resources. The CE reduces the depletion of natural resources and improves resource performance (Moraga et al., 2019; Ellen MacArthur Foundation, 2013). Furthermore, the purpose of the CE is to decouple economic growth from limited (finite) resources and establish such systems that promote economic, social, and natural capital building (Ellen MacArthur Foundation, 2019; Elia et al., 2017).

The CE emphasizes the need to increase the efficiency of resource use which decreases environmental impact along with increasing the wellbeing of the generations (Magnier, 2017). Shifting from linear to a CE which is restorative, reproductive, and cyclical is beneficial for sectoral, organizational, national, and international borders (Korhonen et al., 2018) as it is cost-effective, curtails down the costs associated with the production of new products, does not generate waste and decreases product loss across the value chain. The CE is based on the principle of the closed loop as it decreases the use of virgin materials. The transition to a CE should not be considered only from a material perspective but it can also have an influential effect on environmental quality and climate change (Demurtas et al., 2015). CE practices can lead to a reduction in energy demand and emissions (IRENA, 2019).

One strand of the literature views decoupling of emissions from economic growth as a prime need of the contemporary world (Khan & Majeed, 2020). However, growth and emissions come together when growth is based on conventional energy sources such as coal, fossil fuels, and gas consumption. The theoretical debate on economic growth and environmental sustainability could be traced back to the groundbreaking study of Grossman and Krueger (1995) which suggested "an inverted U-shaped association between per capita GDP and environmental pollution". This association is generally referred as the "Environmental Kuznets Curve (EKC)", and a plethora of studies has investigated its validity, however, up until now the empirical literature is not yet definitive (Majeed and Mazhar, 2020). One possible explanation could be that many studies assume the relationship between economic growth and emissions as a natural process. However, it is not correct as Grossman and Krueger (1995) consider the role of public policy that can assure its falling part. In this research, we propose that circular business models and CE practices can play a vital role in confirming emissions abating effect of economic growth.

Another strand of the literature doubts the validity of CE practices for sustainable development. Murray et al. (2017) argued that CE has certain limitations and can lead to many tensions. For example, it excludes social dimension inherent in sustainable development that curbs its ethical elements, and some other inadvertent effects. Similarly, Schroder (2020) asserts its various negative consequences for the developing world, which largely depend on linear sectors. In a recent study Cotta (2020) argued that exports of used "electronic and electric equipment (EEE) and recyclable plastic materials" worsen the environmental problems of importing counties. Hence, an empirical investigation is necessary to better understand the significance of CE. This study provides empirical evidence on the new emerging debate on switching from linear economy paradigm to CE paradigm.

The use of renewable resources for energy generation is a sustainable practice as it does not deplete or degrade and reduces dependence on fossil fuels which pollute the environment. Thus, renewable resources decrease extraction of fossil fuels and help to enhance environmental quality, mitigate climate change, and avoid depletion of limited virgin resources. The contemporary production and consumption practices and resource exploitation methods are not sustainable as they are putting excessive pressure on the ecosystem in terms of resource depletion, biodiversity extinction, climate change, and unsustainable development (Korhonen et al. 2018; Majeed and Mazhar, 2019a). Thus, conserving the ecosystem and achieving sustainable societies require efficient resource utilization, cooperative consumption, and decreasing costs associated with the resource and waste utilization (Korhonen et al. 2018; Kravchenko et al. 2020).

The circular economy practices including biowaste recycling, municipal waste recycling, packaging waste recycling, trade in recyclables, patents related to recycling, and municipal waste generation can alleviate the pressure on the ecosystem and can conserve the environmental quality. Furthermore, such practices maximize product value by promoting product reuse and lowering the demand for new products. Consequently, new extraction for more production is decreased and prospective emissions are mitigated. Therefore, CE helps in climate neutrality and promotes the use of resources within the threshold level and does not exceed the planetary boundaries. With this background, this study investigates how the CE contributes to environmental mitigation over the period 1990-2014. This study addresses the following research questions:

- How does renewable energy affect environmental quality?
- Does the effect of renewable energy vary across different income groups?
- Does renewable energy matter for CE practices?
- How do CE indicators influence the environment?
- Which dimensions of CE are more important to retain environmental quality?

This research is useful for policymakers, environmental researchers, energy economists, government officials, social scientists, industrial managers, and development practitioners. This is a pioneer empirical study on the usefulness of diverse indicators of CE in a global setting. The findings of the study can be utilized to manage sustainable development goals and global emissions targets. Furthermore, clean energy management strategies can be better implemented and managed by linking the energy sector with CE practices. The empirical estimates are also useful in a comparative setting as trade-offs among alternative CE measures can be better settled.

This study contributes to the literature in the following ways. First, this study is a pioneering study that blends two global issues namely renewable energy-environment nexus and circular economy-environment nexus in a single paper. Second, to the best of our knowledge, we are the first who provide an empirical analysis of CE indicators. Third, this study provides both global evidence and evidence from heterogeneous income groups on renewable energy and the environment nexus. Fourth, this study also improves the methodological part of the paper by applying the Second Gen Panel time series analysis which deals with the issue of temporal and cross-sectional dependence in panel data analysis. Fifth, this study also exploits the dynamic heterogeneous nature of relationships by using common correlated effects mean group (CCEMG) and dynamic CCEMG estimation procedures which allow slope heterogeneity and cross-sectional dependence. Sixth, this study sets a heterogeneous evaluation of renewable energy and circular economy in a comparative setting according to income levels. Seventh, this study provides analytical insights on the different dimensions of the CE indicators.

The study is organized as follows: 2nd section provides a detailed discussion of the literature related to the circular economy. The 3rd section is comprised of data, variable description, and methodology. The 4th section is based on results and discussion and the 5th section will conclude the work.

2. Literature Review

European Commission (2015) explains CE as "*an economy where the value of products, materials, and resources is maintained in the economy for as long as possible, and the generation of waste minimized*". Thus, CE represents a process that retains value (Haupt & Hellweg, 2019) and enhances social and economic dimensions. The CE provides multiple benefits by reducing mining of virgin materials, abating soil and water pollution, controlling ecosystem damage, and discouraging the use of plastic. (Material Economics, 2018; Schroeder et al., 2019). Thus, as CE promotes circular practices and return of material in the form of input to nature and manages waste, it can save the loss of income due to endangered marine species as some 880 million people are dependent on fisheries and aquaculture for their livelihood (FAO, 2016). Another important component of CE is resource efficiency. A resource-efficient economy optimizes production and consumption concerning resource use and decreases energy and material use, resource-saving (dematerialization), remanufacturing, recycling, and reusing (rematerialization) along with infrastructure transitions (IRP, 2017) and decreases waste generation. Figure 3 summarizes the importance of CE for economic, social, and environmental gains.

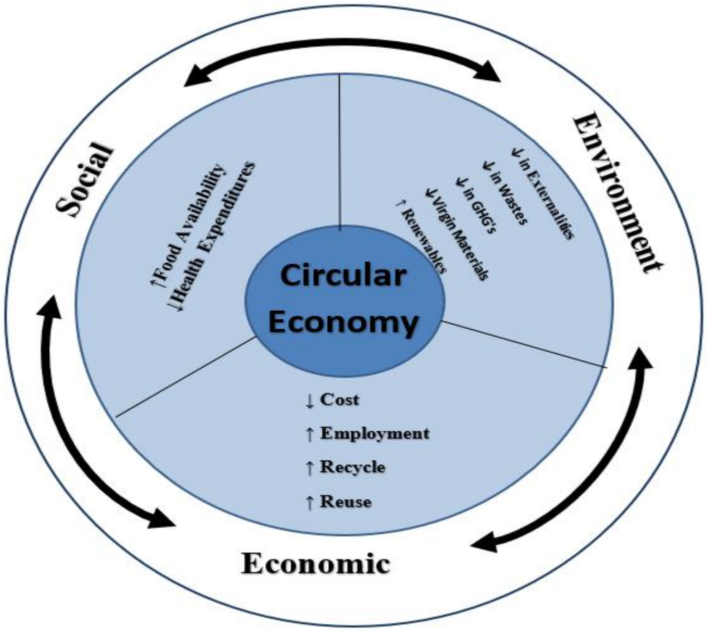

Figure 3: Circular Economy

2.1 Theoretical Perspectives

The sustainable development theory posits that anthropogenic activities need to be managed in such a way that the present generation make an efficient and sustainable utilization of natural resources and ecosystem services without compromising the need for future generations. That is, achieving and managing the dynamic allocative efficiency in the use of resources can preserve the environment and attain sustainable development.

The eco-industrial development theory asserts cascading of matter energy either between industrial ecosystem members or natural system, and cooperation among the companies (so that resources can be used at a rate at which they are replenished). The waste of a company is used as input in another company, thus minimizing the concept of waste generation. Industrial ecology promotes efficiency at a regional scale rather than a firm level. The eco-industrial development promotes efficient sharing of resources including "information, materials, water, energy, infrastructure and natural habitat supporting economic and environmental gains along with human resource enhancement (Deutz & Gibbs, 2008).

The ecological modernization theory explains the links between environmental quality and CE practices. The theory advocates that initially when economies grow, due to rapid industrialization environmental quality degrades. But with further growth, technological development takes place and leads to an improved relationship between industrialization and the environment, enhancing environmental quality. Improvement in environmental quality results from technological advancements, society's role in restructuring and ecological reforms, political measures to improve environmental quality, and change in consumer and producer behavior leading to sustainable practices that enhance environmental quality. Furthermore, public awareness about the environmental importance also leads to the use of eco-friendly technologies thus resulting in improved environmental quality (Majeed & Luni, 2019; Majeed & Mazhar, 2019b; Majeed & Tauqir, 2020).

The "structural and contingency theories" suggest that business corporations consistently review the best resource bundling and frequently reallocate internal resources to become compatible with environmental needs and follow circular business model (Lahti et al., 2018). The "transaction cost theory" explains how companies can close material loops and improve alliances to manage adaption and pressures ascending from sustainability requirements and environmental obligations in the value chain (Argyres, & Mayer, 2007). The "resource-based theory" postulates that constructing and complementing a firm's resource portfolio offers a sustainable gain to initiate and adapt a circular business model (Sirmon et al., 2007). The network theory posits that new networks are developed when firms implement CE business practices and contract-related costs are lowered due to certain network feature such as trust and information sharing norms. The "agency theory" postulates that the agent (customer) can misbehave by, for example, "inappropriately handling, damaging, or overusing product" (Eisenhardt, 1989). In such situation monitoring and incentives can support CE business models by enhancing the probability that assets are recycled and reused.

2.2 Circular Economy and the Environment

Climate change has raised concerns over the "take-make-waste" economy around the globe. The extractive economy uses the resources in an unsustainable way that damages the resource and emits GHGs, therefore, is a hurdle in the way of achieving the 1.5˚C target of the "Paris Agreement". Achieving the target and minimizing the net emissions to zero by 2050 need drastic measures and a projected cost of USD 54 trillion (by 2100) will be borne by the global economy related to climate change which will keep on increasing with temperature changes (Ellen MacArthur Foundation, 2019).

The unsustainable resource use in the traditional economy (take-make-dispose) poses a threat to the survival of 1 million plants and animals that are endangered due to climate change. About 90% of land and water degradation is related to resource extraction and agriculture is the major driver behind that deterioration (biodiversity loss and deteriorating quality and decreasing water availability) (Ellen MacArthur Foundation, 2019).

About 55% of global emissions result from the transport and buildings sector while the remaining 45% originate from land management and output production. Thus, a quarter of global emissions is caused by each: industrial sector and “Agriculture, Forestry, and Other Land Use (AFOLU)”. The take-make-waste concept of the linear economy needs to be remodeled in such a way that it has regenerative capacity. For this purpose, the CE is an important concept in this direction.

For better environmental quality sustainable production and consumption patterns should be followed. Sustainable consumption means consumption that leads to less waste, societal well-being, and resource efficiency (getting more out of less) and consuming in a way that has a minimum negative environmental impact (Tunn et al. 2019). To support the CE not only sustainable consumption but business models are required that increase the life of the product and utilization, narrow down the resource loop, thus enhancing resource and economic efficiency and decreasing environmental losses. However, productivity improvement can lead to rebound effects by increasing consumption (Murray et al., 2017).

2.3 Renewable Resources and Circular Economy

CE assessment comprises renewable energy use. For example, Elia et al. (2017) argued that CE requires the “increased share of renewable and recyclable resources” including renewable energy. Ellen MacArthur Foundation (2015) quoted “replacing fossil fuels with renewable energy” as an example of the principles behind CE. The expectation is that “the adoption of CE will fundamentally transform economic activities away from reliance on non-renewable and emissions-intensive carbon flows towards more sustainable production and consumption” (Korhonen et al., 2018).

Schroeder et al. (2019) argued that CE economy practices such as “maximization of material and energy efficiency, creating value from waste, or applying biomimicry principles to move from nonrenewable to renewable resources” are important CE, business models. The CE not only focuses on the development of such technologies and models that keep the material in circulation, but it also comprises the concepts of “designing out waste, substituting renewable materials for non-renewable ones, and restoring natural systems” (Schroder, 2020).

An effective CE needs a global approach to resource efficiency to take care of the use of raw materials and energy sources. That is, energy should be based on renewable sources. The CE, renewables, and energy efficiency are interconnected to maintain sustainable development. The firms powering the production of global resources are increasingly searching for solutions to meet market demand by minimizing energy usage and environmental problems. Many corporations are trying to “blend the CE with the bio-economy” to align their operations towards a sustainable closed system. That is, an increasing reliance on renewables can facilitate the objectives of the CE.

The growth of renewable resources supports carbon absorption. Renewable resources perform the function of carbon storage and when these resources are converted to waste (through use) they do not contribute to emissions in the atmosphere like fossil-based products (Harris & Rydberg, 2018). Among renewable resources, forestation contributes to the bioeconomy and is a major source of carbon capture.

Renewable power technologies are reliable and increase access as 1 billion people lack a reliable supply of energy. A 1.3% annual increase in energy-related emissions is reported during the last five years which can be controlled through lifestyle changes which include reduction, reuse, and recycling of resources, virgin materials, and water, respectively. Furthermore, structural changes also enable energy efficiency. Such changes include shifts in transportation (public transport and shared passenger cars) and relocation of industrial units to places abundant in renewable resources (IRENA, 2019).

2.4 Circular Economy and Sharing Models

The CE offers the potential to reduce the cost associated with accessing goods and services. Access is preferred over ownership as it reduces the costs, shifts from the use of primary to secondary material of high quality, and the use of digital technologies can facilitate the reduction of waste in the supply chain. Sharing models, public transport, and electrical mobility can enhance the utilization of vehicles, alleviate costs associated with vehicle use, and reduce use and extraction of finite resources, emissions, and congestion (Ellen MacArthur Foundation & McKinsey Center for Business and Environment, 2015).

The CE includes service models such as sharing, renting, paying peruse which not only enhance utilization but also increase the lifespan of the product. When products are kept in use over a longer period the need to replace and produce a new product is decreased. This supports a reduction in emissions which would have been higher if new products were produced (Heyes et al., 2018). Thus, to promote CE, the product-service system (PSS) is a solution and can be enhanced through digitalization. Digitalization facilitates energy efficiency, efficient capacity utilization, and optimize product life cycle (Majeed, 2018; Antikainen et al., 2018).

2.5 Dimensions of Circular Economy

CE practices can be monitored and tracked using the following four dimensions: 1) production and consumption; 2) waste management; 3) secondary raw materials and 4) innovation and competitiveness.

2.5.1 Circular Economy and Efficient Production and Consumption

Production and consumption include self-sufficiency for raw material, generation of municipal water per capita, generation of waste excluding major mineral waste per unit of GP, generation of waste excluding major mineral waste per domestic material consumption, and food waste. Reusing the same material leads to less production of the same material and causes a reduction in GHG emissions associated with its production. The business models that enhance resource efficiency support economic and environmental sustainability respectively (Murray et al., 2017).

As a result of circular practices, the value of products is preserved in the form of energy, labor, and material. Thus, durability and recyclability offer circulation within the economy instead of generating waste. The CE effectively uses biological materials for different economic activities before the nutrients are returned to the natural environment. Thus, the process preserves the energy within the materials and products.

Stahel and Reday (1976) introduced CE practices for industrial economies considering the loop economy. According to the authors, the loop economy promotes waste reduction, increases employment, enhances resource efficiency, and decreases the use of virgin materials in the industrial sector. Furthermore, Stahel (1982) also mentioned the sale of the utilization of the product instead of ownership can minimize costs and externalities associated with production and will also reduce the environmental burden.

The biological materials and food are composted in the biological system through anaerobic digestion. These biological systems strengthen the regenerative capacity of the living system thus providing an economy with renewable resources (Ellen MacArthur Foundation, 2019). Some bio-based plastics have the potential to reduce emissions by 2.2kg of "CO_2e per kg of bio-based polyethylene (PE) produced*".* While using renewables such as wood it is important to make sure that these are sourced from sustainable plantation otherwise illegal use will endanger natural carbon sinks (forests) and biodiversity that is dependent on these resources furthermore these resources cannot be restored easily. An unsustainable harvest of wood has adverse effects on the environment. Bamboo is a fast-growing renewable material and possesses the potential to decrease "2.6 tons of carbon per acre*"* annually.

Regenerative farming not only reduces emissions but also s*equesters carbon in soils and plant matter.* To use regenerative agriculture soil disturbances must be minimized along with an increase in soil carbon content. Regenerative agriculture improves soil structure to store water and promote soil fertility. Regenerative practices include using "organic fertilizers, planting cover crops, employing crop rotation, reducing tillage, and cultivating more crop varieties to promote agro-biodiversity".

The CE paves the path towards "resource-efficient economies". As the CE is based on the cradle to cradle approach, therefore, it aims at the provision and use of resources in such a way that materials and products are made and reused in a manner that does not endanger human health and the environment. All materials are treated as nutrients that can be reused by the production or biological system, respectively.

2.5.2 Circular Economy and Waste Management

Waste management includes the recycling rate of municipal waste, the recycling rate of all waste excluding major mineral waste, the recycling rate for overall packaging, the recycling rate for plastic and wooden packaging, the recycling rate of e-waste, recycling of biowaste, the recovery rate of construction and demolition (C&D) waste.

The circular designs increase the life span of the products and promote regeneration of natural systems facilitating carbon capture in the soil, therefore decreasing externalities, waste generation, and emissions, respectively (Ellen MacArthur Foundation, 2019). Reduction in the production of single-use plastic not only decreases costs but also mitigates waste generation and emissions and other associated externalities (Ellen MacArthur Foundation, 2014).

Furthermore, the circular economy emphasizes value generation from waste. Waste products can be used as inputs in the manufacturing process. In waste management 3Rs (reduce, reuse, recycle) play an important role as recycling of the products leads to a reduction in the extraction of natural resources and decreases costs associated with the production of new products and costs associated with disposal.

The CE practices ensure efficient utilization of natural resources by minimizing waste generation along with other negative externalities. Consequently, the loss of biodiversity and land degradation can be controlled. As most of the basic services are provided by the land, its function as a carbon sink can be improved by lowering its degradation (IPCC, 2019; UN General Assembly, 2015).

2.5.3 Circular Economy and Secondary Raw Material

Secondary raw material includes the end of life recycling input rate, circular material use rate, trade-in recyclable raw material. Recycling and reuse of products across the value chain and conversion of waste through management into a resource represent the circularity of the economies (Elia et al., 2017).

Recycling is an important dimension of the CE as it promotes the sustainability of resources. The industrial symbiosis is at the core of CE which indicates the use of wastes of one firm as a resource by others and tries to minimize waste output. The purpose is to increase the life of the product through improved production technologies and maintenance to decrease the replacement of the product and resource use. The three Rs (reduce, reuse, and recycle) are at the core of the CE (Murray et al., 2017). The substitution of the single-use bottle with “refill” designs in packaging, personal care, beauty products, and home cleaning and transport saving can mitigate GHGs by 80-85% (Ellen MacArthur Foundation, 2019).

2.5.4 Circular Economy and Competitiveness and Innovations

Competitiveness and innovation include patents related to recycling or secondary raw material, gross investment in tangible goods, persons employed, and value added at factor cost (Ekins et al., 2019). Innovations and technological advancements promote resource efficiency and decrease environmental degradation. The CE has the potential to reduce energy consumption through increasing efficiency in resource and material use resulting from innovations in the industrial sector. The advancement in “digital and communication technologies” promotes higher connectivity and reduces energy consumption associated with the transport of heavy goods (Majeed, 2018). The construction of buildings on zero energy standards will reduce energy demand in extreme temperature zones. Advancement and introduction of modern technologies in cooking appliances such as electric stoves and liquefied petroleum gas (LPG) will reduce reliance on traditional bioenergy sources.

The electrification of public buses in Shenzhen in 2017 led to a reduction in emissions and noise pollution and enhanced environmental quality. The introduction of new models promoted the manufacturing of vehicle components that can be used for a longer time, thereby retaining value and promoting electric mobility. Almost 16000 electric buses are providing services in the city thus minimizing noise and heat and contributing to a decline in noise pollution along with the heat island effect. The CE can lead to “rebound effects”. The increase in the efficiency of secondary production supports a decrease in cost and end value of the product and ultimately will boost consumption (rebound effect) and spur economic growth. Thus, enhanced efficiency and environmental improvement can be compromised due to higher growth (Millar et al., 2019). The aforementioned studies highlight the importance of CE and its different dimensions for environmental quality. However, to the best of the authors' knowledge, an empirical evince on the diverse indicators of CE is not yet available. The present study, therefore, provides an empirical analysis on CE and the environment nexus using a global panel of 131 countries and heterogenous income groups.

3. Data, Variable Description, and Methodology

The current study used the data of 131 countries from World Bank, (2020) and used classification of World Bank for income level (high income, upper middle income, lower middle income, and low-income group) and analyzed different income groups that how CE influences environmental quality. To fulfill our purpose the variables used for the study are "carbon dioxide emissions (metric tons per capita)", "GDP per capita (constant 2010 US dollar)", "circular economy", "energy intensity (per capita)", and "urbanization". Renewable energy is used as a proxy of CE. The number of economies in different income groups comprise high-income group consist of 45 economies, upper-middle-income consists of 43 economies, lower-middle-income consists of 12 economies. The analysis is based on 131 countries as data on renewable energy is available for only these countries. As the study is based on macro level, therefore study also used macro scale indicators of CE proposed by European Commission (2018).

The CE indicators are available only for 27 European Union (EU) member countries, therefore due to the data limitation other measures of the CE are analyzed only for these EU countries. The selection of specific 27 EU member countries is dictated by the availability of the data. The data of the CE for EU economies is obtained from "Eurostat (2020)". The set of indicators presented by the European Commission (2018) follows RACER criteria that represent "relevant, acceptable, credible, easy and robust" which helps in the evaluation and appropriateness of the indicators in measuring CE (Rincón-Moreno et al., 2020). Five major dimensions of CE used in the study include renewable resources, production and consumption, waste management, competitiveness and innovations, and secondary raw material. These dimensions include both direct and indirect measures of CE.

Renewable resources do not compromise the regenerative capacity of the planet and reduce negative externalities and input use (Suarez-Eiroa et al., 2019). Production and consumption being an important dimension of circular economy explain the changing pattern of production and consumption which results in self-sufficiency in selected raw materials and a decrease in waste generation. The generation of municipal waste is used to examine the contribution of circular economy in improving environmental quality. The decrease in municipal waste generation is an indicator of improved consumption and production.

Waste management informs about the amount of waste recycled and how much waste and wasted material can be used as input in the economic cycle and create value. The indicators used to represent waste management includes municipal waste, bio waste (as biowaste from household is mixed with other wastes and end in a landfill and contributes to climate change) (European Commission, 2018), and packaging waste recycling. Competitiveness and innovation offer ways to increase the "life span of the products through improving design for circularity and increasing reuse, reparability, durability, and upgradability, promoting innovative industrial processes". The study used "patents related to recycling and secondary raw materials" to represent competitiveness and innovations in a circular economy. Secondary raw material leads to a decline in the use of virgin materials; therefore, stable markets are required for it and its progress can be measured through "trade of recyclable raw materials" (European Commission, 2018). The definition, symbols used, and sources of data are mentioned in table 1. The relationship among the variables can be expressed by equation (1)

$$CO_{2it} = f\,(Y_{it}, CE_{it}, EI_{it}, U_{it}) \qquad (1)$$

where CO_{2it} = carbon dioxide emissions per capita, Y_{it} = Gdp per capita, CE_{it} =circular economy, EI_{it} = energy intensity per capita, U_{it}=urbanization.

$$EI_{it} = \frac{Energy\ use\ per\ capita}{GDP\ per\ capita}$$

The variable energy intensity per capita is generated following Lv and Xu (2018). All the variables have been transformed to logarithmic form to control for heteroscedasticity and multicollinearity and after transformation, the relationship can be expressed as

$$lCO_{2it} = \propto_0 + \propto_1 lY_{it} + \propto_2 lCE_{it} + \propto_3 lEI_{it} + \propto_4 lU_{it} + \varepsilon_{it} \qquad (2)$$

i indicates the countries (1,2, …,131) while *t* represents the time under consideration (1990 to 2014), $\propto_0$ and ε_{it} is "the intercept and the error term".

CE can be decomposed into two parts: renewable resources (R) and circular indicators (CI). To estimate the impact of renewable resources on environmental quality at the global level and across different income groups equation (3) is specified.

$$lCO_{2it} = \propto_0 + \propto_1 lY_{it} + \propto_2 lR_{it} + \propto_3 lEI_{it} + \propto_4 lU_{it} + \varepsilon_{it} \qquad (3)$$

CI includes both direct and indirect indicators to measure CE performance in environmental mitigation. To estimate the impacts of CI indicators equation 3 is modified and specified as equation 4. The impacts of direct CE measures on environmental quality is captured by equations 4.1- 4.7.

$$lCO_{2it} = \beta_0 + \beta_1 lY_{it} + \beta_2 lR_{it} + \beta_3 lCI_{it} + \beta_4 lEI_{it} + \beta_5 lU_{it} + \mu_{it} \qquad (4)$$

$$lCO_{2it} = \partial_0 + \partial_1 lY_{it} + \partial_2 lR_{it} + \partial_3 lGMW_{it} + \partial_4 lEI_{it} + \partial_5 lU_{it} + \mu_{it} \qquad (4.1)$$

$$lCO_{2it} = \gamma_0 + \gamma_1 lY_{it} + \gamma_2 lR_{it} + \gamma_3 MWR_{it} + \gamma_4 lEI_{it} + \gamma_5 lU_{it} + \mu_{it} \qquad (4.2)$$

$$lCO_{2it} = \emptyset_0 + \emptyset_1 lY_{it} + \emptyset_2 lR_{it} + \emptyset_3 BWR_{it} + \emptyset_4 lEI_{it} + \emptyset_5 lU_{it} + \mu_{it} \qquad (4.3)$$

$$lCO_{2it} = \sigma_0 + \sigma_1 lY_{it} + \sigma_2 lR_{it} + \sigma_3 PWR_{it} + \sigma_4 lEI_{it} + \sigma_5 lU_{it} + \mu_{it} \qquad (4.4)$$

$$lCO_{2it} = \varphi_0 + \varphi_1 lY_{it} + \varphi_2 lR_{it} + \varphi_3 EWR_{it} + \varphi_4 lEI_{it} + \varphi_5 lU_{it} + \mu_{it} \qquad (4.5)$$

$$lCO_{2it} = \pi_0 + \pi_1 lY_{it} + \pi_2 lR_{it} + \pi_3 CM_{it} + \pi_4 lEI_{it} + \pi_5 lU_{it} + \mu_{it} \qquad (4.6)$$

$$lCO_{2it} = \rho_0 + \rho_1 lY_{it} + \rho_2 lR_{it} + \rho_3 CDR_{it} + \rho_4 lEI_{it} + \rho_5 lU_{it} + \mu_{it} \qquad (4.7)$$

Where, GMW represents "municipal waste generation", MWR represents "municipal waste recycling", BWR represents "biowaste recycling", PWR represents "packaging waste recycling", EWR represents "e-waste recycling, CM represents "circular material use rate" and CDR represents "construction and demolition recovery rate". CE indicators help in emission mitigation both directly and indirectly. So, if only direct measures are used, we may overlook the impact of indirect CE indicators on emissions, therefore, it is important to investigate the impact of indirect measures as well. To examine the impact of indirect CE indicators on environmental quality equation 4.8 and 4.9 are estimated.

$$lCO_{2it} = \delta_0 + \delta_1 lY_{it} + \delta_2 lR_{it} + \delta_3 RP_{it} + \delta_4 lEI_{it} + \delta_5 lU_{it} + \epsilon_{it} \quad (4.8)$$

$$lCO_{2it} = \vartheta_0 + \vartheta_1 lY_{it} + \vartheta_2 lR_{it} + \vartheta_3 lRT_{it} + \vartheta_4 lEI_{it} + \vartheta_5 lU_{it} + \epsilon_{it} \quad (4.9)$$

RP represent "recycling patents" and RT represent "recyclables trade". To examine the combined effect of different CE measures, indexes are constructed based on averages, and equations 4.10, 4.11, and 4.12 are estimated.

$$lCO_{2it} = \tau_0 + \tau_1 lY_{it} + \tau_2 lR_{it} + \tau_3 AMPWR_{it} + \tau_4 lEI_{it} + \tau_5 lU_{it} + \omega_{it} \quad (4.10)$$

$$lCO_{2it} = \psi_0 + \psi_1 lY_{it} + \psi_2 lR_{it} + \psi_3 lABTMP_{it} + \psi_4 lEI_{it} + \psi_5 lU_{it} + \omega_{it} \quad (4.11)$$

$$lCO_{2it} = \lambda_0 + \lambda_1 lY_{it} + \lambda_2 lR_{it} + \lambda_3 ABMP_{it} + \lambda_4 lEI_{it} + \lambda_5 lU_{it} + \omega_{it} \quad (4.12)$$

In the presence of cross-sectional dependence 1st generation, time series tests cannot be applied. This study, therefore, uses 2nd generation tests to take care of the cross-sectional dependence and slope heterogeneity. The ordinary least squares (OLS) technique does not address the problem of simultaneity and serial correlation between the variables (Pedroni, 2001). Thus, to address these problems, "fully modified ordinary least squares (FMOLS) and dynamic (D)OLS" techniques are employed. The DOLS technique was developed by Stock and Watson (1993) and it provides better results in the presence of cointegration, however, it does not account for cross-sectional heterogeneity.

This study employs following techniques to address the problems of heterogeneous panel data analysis: Mean group (MG) introduced by Pesaran and Smith (1995), Common Correlated Mean Group (CCEMG) introduced by Pesaran (2006), Augmented Mean Group (AMG) introduced by Eberhardt and Bond (2009) and Eberhardt (2012), and Dynamic CCE (DCCE) introduced by Chudik and Pesaran (2015).

Table 1: Variable Description

Variables	Symbols	Definition of Variable	Measurement	Source
Dependent Variable				
Co_2 Emissions	lCO_2	"Carbon dioxide emissions are those stemming from the burning of fossil fuels and the manufacture of cement and the result of anthropogenic activities".	"Metric tons per capita"	WB, 2020
Independent Variables (Focused Variables)				
Renewable Energy	LR	"Renewable energy consumption is the share of renewable energy in total final energy consumption".	"% of total final energy consumpti on"	WB, 2020
Municipal Waste Generation	GMW	"Generation of municipal waste".	Per capita	Eurostat , 2020
Municipal Waste Recycling	MWR	"Recycling rate of municipal waste".	"%"	Eurostat , 2020
Biowaste Recycling	BWR	"Recycling of biowaste".	"kg per capita"	Eurostat , 2020
Packaging Waste Recycling	PWR	"Recycling rate of packaging waste by type of packaging"	"%"	Eurostat , 2020
Recycling Patents	RP	"Patents related to recycling and secondary raw materials".	"Numbers "	Eurostat , 2020
Recyclables Trade	LRT	"Trade in recyclable raw materials".	"ton"	Eurostat , 2020
Ampwr	AMPW R	"Average of municipal waste recycled and packaging waste recycled".	Index	"Constr ucted by authors"
Labtmp	LABT MP	"Average of biowaste recycling, trade of recyclables, municipal waste recycled and packaging waste recycled".	Index	"Constr ucted by authors"
Abmp	ABMP	"Average of biowaste, municipal waste and packaging waste".	Index	"Constr ucted by authors"
E-Waste Recycling	EWR	"Recycling rate of e-waste".	"% of total e-waste"	Eurostat , 2020
Circular Material	CM	"Circular material use rate".	"% of total material use"	Eurostat , 2020

Construction and Demolition Recovery	CDR	"Recovery rate of construction and demolition waste".	"% of construction and demolition mineral waste recycled"	Eurostat, 2020
Independent Variables (Control Variables)				
GDP Per Capita	LY	"GDP per capita is gross domestic product divided by midyear population".	"Constant 2010 US$"	WB, 2020
Energy Intensity	LEI	"Energy consumption per capita divided by GDP per capita".	"Per capita"	Constructed by authors
Urbanization	LU	"Urban population refers to people living in urban areas".	"% of total population"	WB, 2020
Energy Use	EU	"Energy use refers to use of primary energy before transformation to other end-use fuels".	"kg of oil equivalent per capita"	WB, 2020
Other Variables				
Trade	T	"Trade is the sum of exports and imports of goods and services measured as a share of gross domestic product".	"% of GDP"	WB, 2020
Foreign Direct Investment	FDI	"FDI is the net inflows (new investment inflows less disinvestment) in the reporting economy from foreign investors, and is divided by GDP".	"% of GDP"	WB, 2020
Forest Area	FA	"Forest area is land under natural or planted stands of trees and excludes tree stands in agricultural production systems and trees in urban parks and gardens".	"% of land area"	WB, 2020
Agriculture Land	AL	"Agricultural land refers to the share of land area that is arable, under permanent crops, and under permanent pastures".	"% of land area"	WB, 2020

4. Results and Discussion

As countries are engaged in trade and policies of one country has implications for others, therefore, cross sectional dependence should be examined in panel data. The results obtained without examining cross-sectional dependence results in biased analysis. To test for cross-sectional dependence, "Breusch- Pegan LM, Pesaran scaled LM, Bias-corrected, and Pesaran CD test" have been used. The Breusch and Pegan (1980), "LM test" is examined by equation (5) mentioned below:

$$LM_{BP} = T\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\hat{\rho}^{2}{}_{ij} \qquad (5)$$

As n approaches infinity the "LM test" cannot be applied, therefore, "scaled version of LM" proposed by Pesaran (2004) is used (equation 6).

$$BP_{s} = \sqrt{\frac{1}{N(N-1)}}\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}(T\hat{\rho}^{2}{}_{ij} - 1] \qquad (6)$$

When t is finite and n is large the "BPs test" is distributed asymptotically N (0, 1), but with increase in n, normal approximation is not appropriate as BPs not centered at zero and leads to distortions. Therefore, Pesaran et al. (2008) introduced "bias-corrected scaled LM statistics" which can be estimated by the equation (7)

$$LM_{BC} = LM_{P} - \frac{n}{2(T-1)} = \sqrt{\frac{1}{N(N-1)}}\;[\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}(T\rho^{2}{}_{ij} - 1] - \frac{N}{2(T-1)} \qquad (7)$$

The study used Pesaran (2004) "CD test". The "CD test" can be presented by the equation (8)

$$CD = \sqrt{\frac{2T}{N(N-1)}}\sum_{i=1}^{N-1}\sum_{k=i+1}^{N}\hat{\rho}_{it} \qquad (8)$$

T represents time and N is used for the sample size, T shows the time, and $\hat{\boldsymbol{\rho}}$ indicates "correlations among errors of different cross-sections of country i and k". Table 2 reports the outcomes of cross-sectional dependence tests. The tests conclude the presence of cross-sectional dependence as the null hypothesis of no cross-sectional dependence is rejected at a 1% level of significance by all tests.

Table 2: Results of Cross-Sectional Dependence Test

Variables	Breusch-Pegan LM	Pesaran scaled LM	Bias-corrected scaled LM	Pesaran CD
General Panel (131)				
CO_2 Emissions per capita	58862.06***	385.80***	383.07***	22.70***
GDP per capita	133040.4***	954.22***	951.49***	277.58***
Renewable Energy per capita	67241.93***	450.02***	474.29***	41.34***
Energy intensity per capita	99528.40***	697.42***	694.69***	151.06***
Urbanization	158445.4***	1148.90***	1146.17***	214.78***
High Income (45)				
CO_2 Emissions per capita	6227.66***	117.70***	116.77***	19.72***
GDP per capita	18580.21***	395.31***	394.37***	114.31***
Renewable Energy per capita	10571.88***	215.33***	214.39***	64.22***
Energy intensity per capita	14794.56***	310.23***	309.29***	76.75***
Urbanization	16996.83***	359.73***	358.79***	49.51***
Upper Middle Income (43)				
CO_2 Emissions per capita	5607.82***	110.71***	109.81***	18.13***
GDP per capita	15024.38***	332.29***	331.39***	106.25***
Renewable Energy per capita	5523.10***	108.71***	107.82***	0.83
Energy intensity per capita	8768.82***	185.09***	184.19***	42.47***
Urbanization	16837.19***	374.94***	374.05***	77.62***
Lower Middle Income (31)				
CO_2 Emissions per capita	4519.54***	132.95***	132.30***	24.16***
GDP per capita	7900.89***	243.83***	243.18***	70.75***
Renewable Energy per capita	3500.32***	99.53***	98.88***	0.94
Energy intensity per capita	5036.70***	149.91***	149.26***	33.82***
Urbanization	8940.88***	277.93***	277.28***	56.91***
Low Income (12)				
CO_2 Emissions per capita	486.61***	36.61***	36.36***	3.95***
GDP per capita	498.29***	37.63***	37.37***	4.43***

Renewable Energy per capita	478.82***	35.93***	35.68***	-0.82
Energy intensity per capita	634.12***	49.45***	49.19***	-0.36
Urbanization	1454.86***	120.88***	120.63***	26.51***
European Union Member Countries (27)				
CO_2 Emissions per capita	2560.08***	83.38***	82.41***	36.48***
GDP per capita	3121.21***	104.56***	103.59***	49.15***
Renewable Energy per capita	3715.26***	126.98***	126.01***	60.21***
Energy intensity per capita	3669.55***	125.25***	124.29***	59.45***
Urbanization	4283.93***	148.44***	147.48***	15.12***
Trade in recyclable materials	1218.29***	32.73***	31.77***	2.97***
Patents related to recycling	490.17***	5.26***	4.29***	5.06***
Biowaste recycling	2244.05***	71.45***	70.48***	19.95***
Municipal waste recycling	2496.85***	80.99***	80.03***	36.68***
Packaging waste recycling	2247.44***	71.58***	70.61***	40.21***
ABMP	2670.14***	87.53***	86.57***	35.91***
AMPWR	3128.75***	104.84***	103.87***	49.04***
LABTMP	1244.13***	33.71***	32.75***	2.95***
Municipal waste generation	1323.36***	36.40***	25.74***	13.49***
Probabilities represented by * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$				

In the next step, we proceed with 2nd generation tests. Table 3 presents the results obtained from the "cross-sectionally augmented IM Pesaran and Shin (CIPS) test" introduced by Pesaran (2007) and "cross-sectionally augmented ADF (CADF) unit root test"**.** This method controls the cross-sectional dependence while examining the integration order. The equation (9) used for CIPS is given as follows

$$\Delta Y_{it} = \gamma_{it} + x_i\, Y_{i,t-1} + \lambda_i T + \sum_{k=1}^{n} \pi_{ik}\, \Delta Y_{i,t-k} + \mu_{it} \tag{9}$$

Here, subscripts 'i' and't' represent "the intercept and time trend". CADF test is also used to examine stationarity. The "Augmented Dickey-Fuller" regression is performed by adding lagged levels ($\overline{X}_{t-1}$) of cross-sectional averages and first difference value of all series. Equation 10 is used for the "CADF test".

$$\Delta X_{it} = \propto_i + \beta_i X_{i,t-1} + \delta_i \bar{X}_{t-1} + \lambda \Delta \bar{X}_t + \mu_{it} \tag{10}$$

Here, $\overline{X}_t$ represents the average for all observations at time t and "the equation included is a proxy of unobserved effects by common factors."

In the general panel, high-income, and lower-middle-income groups the variables are stationary at the level and 1^{st} difference, however, the variables are stationary at the level in the upper-middle-income group and first difference in the lower-income group respectively. In EU member countries the results suggest that CO_2, BWR, MWR, ABMP, and LGMW are difference stationary while lRT, RP, PWR, AMPWR, LABTMP are level stationary respectively.

Table 3: 2nd Generation Unit Root Results

Variable	CIPS		CADF	
General Panel (131)				
	Level	**1st Difference**	**Level**	**1st Difference**
CO_2 emissions per capita	-2.053	-4.762***	-3.462***	-35.425***
GDP per capita	-2.086**	-3.642***	-3.850***	-22.207***
Renewable energy per capita	-2.288***	-4.683***	-6.228***	-34.491***
Energy intensity per capita	-2.403***	-4.709***	-7.593***	-34.803***
Urbanization	-1.934	-1.642	-2.058**	-1.398
"Critical values -2, -2.05, -2.14 at 10%, 5%, 1% in CIPS and CADF having -2.000, -2.050, -2.140 at 10%, 5%, and 1% level of significance, respectively"				
HY (45)				
CO_2 emissions per capita	-1.826	-4.936***	-0.460	-21.964***
GDP per capita	-1.589	-3.543***	1.186	-12.333***
Renewable energy per capita	-2.455***	-4.938***	-4.806***	-21.977***
Energy intensity per capita	-2.622***	-5.104***	-5.963***	-23.127***
Urbanization	-0.509	-1.536	8.651	1.550
UMY (43)				
CO_2 emissions per capita	-2.469***	-4.907***	-4.793***	-21.275***
GDP per capita	-2.500***	-4.046***	-5.000***	-15.452***
Renewable energy per capita	-2.345***	-4.691***	-3.952***	-19.815***
Energy intensity per capita	-2.263***	-4.597***	-3.404***	-19.182***
Urbanization	-1.479	-1.618	1.901	0.960
LMY (31)				
CO_2 emissions per capita	-1.826	-4.885***	-0.377	-17.936***
GDP per capita	-1.729	-3.790***	0.178	-11.654***
Renewable energy per capita	-1.483	-4.743***	1.590	-17.122***
Energy intensity per capita	-2.387***	-4.547***	-3.599***	-15.998***
Urbanization	-2.643***	-1.450	-5.067***	1.778
"Critical values -2.04, -2.11, -2.23 at 10%, 5%, 1% in CIPS and CADF having -2.040, -2.110, -2.230 at 10%, 5%, and 1% level of significance respectively."				
LY (12)				
CO_2 emissions per capita	-1.541	-3.977***	0.819	-7.881***
GDP per capita	-1.711	-4.184***	0.210	-8.622***
Renewable energy per capita	-1.122	-4.008***	2.314	-7.992***

Energy intensity per capita	-1.411	-4.227***	1.283	-8.774***
Urbanization	-0.817	-1.764	3.405	0.022
"Critical values -2.14, -2.25, -2.45 at 10%, 5%, 1% in CIPS and CADF having -2.140, -2.250, -2.450 at 10%, 5%, and 1% level of significance respectively".				
European Union Member Countries (27)				
CO_2 emissions per capita	-2.137*	-4.170***	-1.971**	-11.572***
GDP per capita	-1.465	-2.532***	1.203	-3.837***
Renewable energy per capita	-2.230**	-3.527***	-2.410***	-8.538***
Energy intensity per capita	-2.180**	-3.497***	-2.174**	-8.392***
Urbanization	-1.162	-1.848	2.638	-0.605
Direct indicators				
Municipal waste generation	-1.868	-3.811***	-0.699	-9.875***
Municipal waste recycling	-1.807	-3.422***	-0.413	-8.038***
Biowaste recycling	-1.677	-3.947***	0.201	-10.518***
Packaging waste recycling	-2.855***	-4.096***	-5.360***	-11.224***
Indirect indicators				
Recycling patents	-3.063***	-4.574***	-6.343***	-13.482***
Recyclables trade	-2.311**	-3.540***	-2.791***	-8.598***
Indexes				
AMPWR	-2.509***	-3.861***	-3.729***	-10.114***
LABTMP	-2.311*	-3.519***	-2.793***	-8.498***
ABMP	-.2.146*	-3.688***	-2.011**	-9.298***
"Critical values -2.07, -2.17, -2.34 at 10%, 5%, 1% in CIPS and CADF having -2.070, -2.170, -2.340 at 10%, 5%, and 1% level of significance respectively. GP: General panel, HY: High income, UMY: Upper middle income, LMY: Lower middle income"				

Table 4 presents the results obtained from the "Westerlund (2007) cointegration test", which considers cross-sectional dependence, unit-specific short-run dynamics, and trend and slope parameters. The test provides four results two results examine the alternative hypothesis that the whole panel is cointegrated while the other two examine that at least one unit is cointegrated (Ehigiamusoe & Lean, 2019). The test is performed with zero lag and lead and results confirms cointegration. The results support cointegration in the general panel and all income groups. Thus emissions, GDP per capita, renewable energy consumption, and urbanization are co-integrated.

Table 4: Wester-Lund Cointegration Results

	Value	Z-Value	P-Value	Bootstrap P-Value
GP (131)				
Group-tau	-4.323	-22.500	0.000	0.000
Group-alpha	-7.767	7.752	1.000	0.040
Panel- tau	-106.182	-75.320	0.000	0.000
Panel-alpha	-21.478	-18.375	0.000	0.000
HY (45)				
Group-tau	-3.012	-3.983	0.000	0.000
Group-alpha	-8.334	4.047	1.000	0.020
Panel- tau	-15.945	-1.416	0.079	0.200
Panel-alpha	-6.757	2.255	0.988	0.460
UMY (43)				
Group-tau	-4.694	-15.440	0.000	0.000
Group-alpha	-8.996	3.389	1.000	0.000
Panel- tau	-121.351	-99.017	0.000	0.000
Panel-alpha	-40.011	-26.557	0.000	0.000
LMY (31)				
Group-tau	-3.349	-5.269	0.000	0.000
Group-alpha	-5.869	5.150	1.000	0.870
Panel- tau	-11.254	0.654	0.743	0.350
Panel-alpha	-4.334	3.651	1.000	0.870
LY (12)				
Group-tau	-10.421	-28.933	0.000	0.000
Group-alpha	-6.139	3.082	0.999	0.680
Panel- tau	-7.842	-0.369	0.356	0.153
Panel-alpha	-5.868	1.571	0.942	0.407
"GP: General panel, HY: High income, UMY: Upper middle income, LMY: Lower middle income"				

Due to the presence of cointegration, the results of "FMOLS and DOLS" are presented in table 5. The FMOLS results show that renewable energy has a negative and significant impact on CO_2 emissions globally and in all income groups. This finding is consistent with Samreen & Majeed (2020) who found similar effect for 89 countries over the period 1992-2014. This indicates that an increase in renewable energy will decrease CO_2 emissions globally regardless of the income differences among the countries. However, the magnitude of the impact of renewable energy on emission mitigation varies across different income groups. The highest impact of renewable energy on emissions reduction is revealed in low-income economies followed by lower middle income, upper middle income, and high-income countries. As low-income countries lack clean energy access, renewable energy causes the strong impact on environmental quality.

The results also suggest an increase in emissions from GDP per capita. An increase in income contributes to higher emissions in low-income economies followed by high income, lower middle income, and upper middle income. The low-income countries use obsolete technologies that deteriorate their environmental quality. The contribution of energy intensity in emissions is high in low-income economies due to a lack of efficiency and modern technologies. The impact of urbanization varies across income groups. Urbanization increases emissions in low-income economies while decreases emissions in other income groups. This finding is inconsistent with Majeed & Tauqir (2020) who found similar effects across different income groups.

Similarly, the findings of DOLS also support the results from FMOLS in terms of the sign as well as statistical significance. Accordingly, the regression coefficient of renewable energy is negative and statistically significant indicating that an increase in the share of renewable energy will improve environmental quality by decreasing carbon dioxide emissions. Renewable energy has a more prominent impact on the environmental quality of low-income countries. The regression coefficients of GDP per capita is highest in low-income countries suggesting that income generation is at the cost of environmental quality. The impact of income on environmental deterioration is lowest in high-income economies. Energy intensity harms the environment of all income groups, however, the effect is more severe in developing economies. The impact of urbanization across different income groups is insignificant while at the global level it is significant and depicting positive relationships.

Table 5: Results of FMOLS and DOLS

"Equation 3"						
Estimator	**Variables**	**GP**	**HY**	**UMY**	**LMY**	**LY**
FMOLS	GDP per capita	1.13***	0.83***	0.67***	0.82***	1.55***
	Renewable energy per capita	-0.42***	-0.12***	-0.19***	-0.79***	-2.08***
	Energy intensity per capita	0.45***	0.74***	0.88***	0.61***	2.07***
	Urbanization	-1.49***	-0.99***	-0.58***	-0.41*	0.26***
DOLS	GDP per capita	1.05***	0.86***	1.33***	1.38***	3.85***
	Renewable energy per capita	-0.15***	-0.10***	-0.11***	-0.49**	-1.85***
	Energy intensity per capita	0.80***	0.75***	1.16***	0.91***	2.90***
	Urbanization	0.53***	-0.33	-0.08	-0.16	-0.18

"Probabilities represented by * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$, GP: General panel, HY: High income, UMY: Upper middle income, LMY: Lower middle income"

The study also employed static models with heterogeneous slopes (MG, AMG, CCE). Pesaran and Smith (1995) Mean group estimator allows "intercept, slope coefficient, and error variances to differ across groups" (Blackburne III & Frank, 2007). Augmented Mean Group (AMG) estimator introduced by Eberhardt and Bond (2009) and Eberhardt (2012), considers "the effects of common shocks by including a common dynamic process" (Shafiei and Salim, 2014*)*. The findings remain consistent with the previous results. Deployment of renewable energy boosts environmental quality and the impact is highest in low-income economies, while income and energy intensity cause environmental degradation across all income groups with severe consequences for low-income countries due to inefficient technologies.

Table 6: Static MG, and AMG Results

		Equation (3)				
Estimator	**Variables**	**GP**	**HY**	**UMY**	**LMY**	**LY**
MG	GDP per capita	1.627***	1.044***	1.005***	1.881***	5.388***
	Renewable energy per capita	-0.828***	-0.143***	-0.280***	-1.419***	-3.837***
	Energy intensity per capita	1.543***	1.106***	0.968***	1.681***	4.889***
	Urbanization	0.016	0.244	-1.055	0.944	0.226
	Constant	-4.998**	-5.990	-0.330	-7.192**	-12.223**
	RMSE	0.103	0.061	0.124	0.109	0.125
	Observations	3275(**131**)	1125(45)	1075(43)	775(31)	300(12)
AMG	GDP per capita	1.672***	1.111***	1.038***	1.966***	5.473***
	Renewable energy per capita	-0.852***	-0.124**	-0.291***	-1.513***	-4.331***
	Energy intensity per capita	-1.558***	1.088***	0.990***	1.736***	5.044***
	Urbanization	-0.438	0.727	-1.3764*	-0.265	-0.419
	Constant	-3.386*	-8.848**	0.5214	-2.476	-9.630*
	RMSE	0.086	0.059	0.0821	0.094	0.103
	Observations	3275(131)	1125(45)	1075(43)	775(31)	300(12)

“Probabilities represented by * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$, GP: General panel, HY: High income, UMY: Upper middle income, LMY: Lower middle income”

According to Pesaran (2006), if cross-sectional dependence is not accounted for, it will lead to biased estimates. Therefore, “the common correlated coefficient (CCE) introduced by Pesaran (2006) and Dynamic (D)CCE introduced by Chudik and Pesaran (2015)” are used which take care of cross-sectional dependence. CCE approach considers unobserved dependencies among the countries in the panel. According to Pesaran (2006), “the model can be consistently estimated by approximating the unobserved common factor with cross-sectional means of the dependent and independent variables under strict exogeneity*”.* The equation (11) used for the estimation of CCE can be written as

$$lY_{it} = \beta_i + \propto_i lX_{it} + \delta_i \overline{lY}_{it} + \lambda_i \overline{lX}_{it} + \varepsilon_{it} \tag{11}$$

where $\mathrm{lY_{it}}$ represents ($\mathrm{lCO_{2it}}$) and $\mathrm{lX_{it}}$ comprises of independent variables (Y_{it}, R_{it}, EI_{it}, U_{it}). *“*The coefficients $\boldsymbol{\delta_i}$ and $\boldsymbol{\lambda_i}$ represent the elasticity estimates of $\mathbf{lY_{it}}$ concerning the cross-sectional averages of the dependent variables and the observed regressors, respectively.*”*

The problem with static models is that it does not account for endogeneity. Therefore, to address this problem we moved towards the dynamic model. The incorporation of the lag of the dependent variable in CCE will make it inconsistent, therefore, dynamic CCE (DCCE) was introduced by Chudik and Pesaran (2015). It allows for heterogeneity in the slope coefficient and computes cross-sectional dependence. It supports both unbalanced and balanced panels and allows for endogenous variables and can be used when time is small (as it has small sample bias correction). The results of CCE and DCCE are presented in table 7. The results remain consistent even different estimators are used. Renewable energy decreases environmental degradation, whereas GDP per capita, and energy intensity increase emissions.

Table 7: Heterogeneous Panel Estimation Results

Equation (3)						
Estimator	**Variables**	**GP**	**HY**	**UMY**	**LMY**	**LY**
CCE	GDP per capita	1.855***	1.132***	1.053***	2.004***	6.403***
	Renewable energy per capita	-0.744***	-0.131***	-0.283**	-1.106***	-4.774***
	Energy intensity per capita	1.617***	1.047***	0.893***	1.675***	5.369***
	Urbanization	-0.911	0.213	-0.163	-0.238	-2.145
	Constant	-5.736	-12.437	-4.816	4.609	-6.732
	RMSE	0.063	0.042	0.070	0.076	0.075
	Observations	3275(131)	1125(45)	1075(43)	775(31)	300(12)
DCCE	Lag of CO_2	-0.053**	-0.004	-0.019	-0.042	0.135
	GDP per capita	2.023***	1.148***	0.994***	2.057***	6.086***
	Renewable energy per capita	-1.171***	-0.187***	-0.229***	-1.141***	-2.731
	Energy intensity per capita	1.731***	1.101***	0.999***	-1.884***	4.554***
	Urbanization	-1.451	-0.576	-0.735	-2.980	-2.536
	MG R^2	0.91	0.84	0.94	0.90	0.94
	RMSE	0.07	0.05	0.05	0.09	0.08
	CD test	0.20	-0.31	-1.08	-1.56	-1.81*
	Observations	3013(131)	1035(45)	989(43)	713(31)	276(12)
“Probabilities represented by * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$, GP: General panel, HY: High income, UMY: Upper middle income, LMY: Lower middle income”						

4.1 Results of Different Indicators of Circular Economy

Finally, the analysis based on the incorporation of different indicators of the circular economy is carried out only for European Union member countries (27) as the data was not available for other countries. The results obtained from Pedroni (1999), Kao (1999), and Westerlund (2007) panel cointegration test suggest cointegration in the panel. The results are presented in Table 8.

Table 8: Results of Cointegration Test

Estimates	Statistics	Probability
“Pedroni Panel cointegration test Ho: No cointegration”		
Alternate Hypothesis: Common AR Coefficients		
Panel v-statistics	-3.2001	1.0000
Panel rho-statistics	5.2967	1.0000
Panel PP statistics	-5.7188	0.0000
Panel ADF statistics	-5.6781	0.0000
Alternate Hypothesis: Individual AR Coefficients		
Group rho-statistics	5.9973	1.0000
Group PP statistics	-23.8311	0.0000
Group ADF statistics	-9.8304	0.0000
“Kao cointegration test Ho: No cointegration”		
ADF	-3.7110	0.0001
“Westerlund cointegration test Ho: No cointegration”		
Variance ratio	-2.1932	0.0141

After determining the cointegration, the study used pooled mean group (PMG) estimation to examine the relationship among the variables in European Union member economies that how different measures of the CE contribute to environmental quality and decrease the extraction of virgin materials by recycling and reuse practices respectively.

The PMG estimator allows “intercept, short-run covariance and error variance to differ however the long-run coefficients are restricted to remain the same across groups”. The impact was analyzed through five major dimensions of CE including renewable resources, production and consumption, waste management, competitiveness and innovations, and secondary raw material. Furthermore, the index has been constructed to examine the combined impact of CE measures on the economy. The results are presented in tables 9a, 9b and 10. Column 1 of Table 9a incorporates renewable energy as an indicator of renewable resources and results support that with the increase in renewable energy, emissions will reduce by 0.065%, respectively. GDP per capita and energy intensity lead to higher emissions while urbanization helps to combat emissions in all regressions.

Column 2 presents the result of production and consumption patterns measured through municipal waste generation. The findings suggest that municipal waste generation lowers emissions by 0.212 % per person. This finding is not consistent with Magazzino et al. (2020) who found emissions augmenting effect of municipal waste generation for Switzerland. Column 3 presents the results of municipal waste recycling and indicates that the coefficient is negative associated with carbon emissions. This effect is, however, insignificant suggesting a certain threshold level is not yet attained which ensures the significant impact. The results reported in column 4 suggest that one percent increase in biowaste recycling enhances environmental quality by 0.001%. This finding is consistent with the findings of Magazzino et al. (2020). In column 5 results indicate that the increase in packaging waste recycling leads to higher emissions. Table 9b indicates that e-waste recycling significantly lowers emissions.

Table 9a: Results of Production, Consumption, and Waste Management

Dependent Variable: Carbon Dioxide Emissions					
	Direct Measures of CE				
Dimensions	Renewable Resources	Production and Consumption	Waste Management		
	Equation (3)	Equation (4.1)	Equation (4.2)	Equation 4.3)	Equation (4.4)
	1	2	3	4	5
Variables	Renewable Energy	Muncipal Waste Generation	Municipal Waste Recycling	Biowaste Recycling	Packaging Waste Recycling
Circular Economy	-0.065***	-0.212***	-0.0017	-0.0005***	0.005***
	(0.0073)	(0.050)	(0.0002)	(0.0001)	(0.0006)
Gdp Per Capita	0.953***	1.031***	0.832***	1.034***	0.777***
	(0.0227)	(0.0342)	(0.0195)	(0.0199)	(0.0430)
Renewable Energy	-	-0.130***	0.010***	-0.078***	-0.429***
	-	(0.0113)	(0.0026)	(0.0061)	(0.0207)
Energy Intensity	1.185***	1.109***	1.091***	1.211***	0.571***
	(0.0236)	(0.0292)	(0.0190)	(0.0208)	(0.0578)
Urbanization	-1.556***	-1.708***	-1.452***	0.518***	1.907***
	(0.1671)	(0.2665)	(0.1032)	(0.1495)	(0.2141)
Observations	378	378	378	378	378
No Of Groups	27	27	27	27	27
Log Likelihood	1186.87	1207.99	1270.32	1233.39	1213.65
Standard Errors In Parentheses * $P < 0.1$, ** $P < 0.05$, *** $P < 0.01$					

Table 9b: Results of Production, Consumption, and Waste Management

	Dependent Variable: lCO_2		
	Direct measures of CE		
Dimensions	**E-waste Recycling (MG)**	**Construction And Demolition Recovery (POLS)**	**Circular Material Use Rate (POLS)**
	Equation 4.5	**Equation 4.6**	**Equation 4.7**
Variables	**1**	**2**	**3**
Circular economy	-0.002*	0.0002	-0.0027
	(0.0707)	(0.0008)	(0.0041)
GDP per capita	1.3113***	1.1065***	1.1101***
	(0.1446)	(0.0892)	(0.0785)
Renewable energy	-0.2223***	-0.2634***	-0.2500***
	(0.0707)	(0.0370)	(0.0285)
Energy intensity	1.265***	1.191***	1.1609***
	(0.1554)	(0.1057)	(0.0894)
Urbanization	-3.061	-0.4747**	-0.3584***
	(4.3620)	(0.1847)	(0.1295)
Observations	182	75	135
No of groups	26	27	27
R^2		0.7505	0.7387
Wald chi2	106.04	-	-
Standard errors in parentheses * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$			

Table 10 presents the results of competitiveness and innovations, secondary raw material, and the index constructed. Column 1 presents the results of patents related to recycling and support reduction in emissions by 0.017% through an increase in patents related to recycling. Our results are consistent with Cainelli et al. (2020) who exhibited that innovation adoption and diffusion by EU firms are the vital pillars of resource efficiency and CE development. Column 2 presents the result of secondary raw material measured through trade in recyclable materials. The coefficient of trade in recyclable material appears with a negative sign however the coefficient is insignificant. This finding is inconsistent with Cotta (2020) who argued that exports of used “electronic and electric equipment (EEE) and recyclable plastic materials” worsen the environmental problems of importing economies. Columns 3, 4, and 5 present the result of the index constructed. The AMPWR and ABMP appear with a negative sign and suggest lower emissions while LABTMP increases emissions.

Among different measures of CE, the impact of recycling patents has more profound impact on improving environmental quality as competitiveness and innovations is at the core of all initiatives to promote sustainability. Innovation offers the path towards improved production techniques and sustainable consumption that results in lower waste generation. Decreasing waste generation indicates the efficiency of resource use within the economies and decreases their dependence on foreign inputs and raw materials. Along with this waste management including municipal waste, biowaste, and packaging waste recycling also offer opportunities for environmental and ecosystem enhancement through decreased waste that ends in landfills and oceans and releases a huge amount of pollutant emissions. Through recycling the need to produce new commodities is reduced which lowers the demand for material extraction, and emissions related to extraction as well as production and consumption patterns. Trade-in recyclables can also help in climate mitigation through decreased demand for virgin materials extracted for trade. As the circular economy retains value of the products for as long as possible, therefore all the measures taken to implement CE practices have a favorable impact on environmental sustainability. The results support that different measures of the circular economy leads to a green economy and promote recycling, thereby supporting the efficient use of resources and environmental preservation. The generation of municipal waste has a more profound impact on controlling emissions than biowaste recycling which is evident from the magnitude of the coefficient (-0.212).

Table 10: Results of Competitiveness and Innovations and Secondary Raw Material

Dependent Variable: Carbon Dioxide Emissions					
Dimensions	**Competitiveness and innovation**	**Secondary raw material**	**Indexes**		
	Indirect measures of CE		**Indexes**		
	Equation (4.8)	Equation (4.9)	Equation (4.10)	Equation (4.11)	Equation (4.12)
	1	**2**	**3**	**4**	**5**
Variables	**Recycling Patents**	**Recyclables Trade**	**AMPWR**	**LABTMP**	**ABMP**
Circular Economy	-0.017***	-0.003	-0.003***	0.016***	-0.002***
	(0.0018)	(0.0053)	(0.0002)	(0.0044)	(0.0003)
GDP per capita	1.079***	0.193	0.884***	1.076***	0.884***
	(0.0224)	(0.1923)	(0.0295)	(0.0322)	(0.0262)
Renewable energy	-0.120***	-0.076***	-0.015***	-0.176***	-0.0227***
	(0.0093)	(0.0220)	(0.0054)	(0.0145)	(0.0069)
Energy intensity	1.048***	1.254***	1.036***	0.904***	1.075***
	(0.0239)	(0.0730)	(0.0223)	(0.0364)	(0.0314)
Urbanization	-1.233***	-0.673*	-1.035***	-1.515***	-0.834***
	(0.0985)	(0.3465)	(0.1025)	(0.1359)	(0.1360)
Observations	378	378	378	378	378
No of groups	27	27	27	27	27
Log Likelihood	1222.312	1210.058	1232.349	1212.119	1240.177
Standard errors in parentheses * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$					

Table 11 reports the results based on sensitivity analysis. For sensitivity analysis trade, FDI, forest area, and agriculture land are used as additional control variables. The analysis confirms that renewable energy decreases emissions globally as well as across all income groups. In EU member countries renewable energy, packaging waste recycling, municipal waste recycling, biowaste recycling, recyclables trade, and CE indexes mitigate environmental degradation while municipal waste generation increases environmental deterioration.

Table 11: Sensitivity Analysis

Sensitivity Analysis				
	Trade	**FDI**	**Forest Area**	**Agriculture land**
Groups analyzed	**Dependent Variable: CO_2 emissions**			
Global Panel	-0.1533***	-0.1584***	-0.1296***	-0.1471***
	(0.0064)	(0.0064)	(0.0070)	(0.0064)
R-Squared	0.8825	0.8826	0.8860	0.8884
High Income	-0.1057***	-0.1006***	-0.0977***	-0.1033***
	(0.0043)	(0.0042)	(0.0044)	(0.0041)
R-Squared	0.8047	0.8016	0.8011	0.8087
Upper Middle Income	-0.1090***	-0.1107***	-0.1082***	-0.1055***
	(0.0090)	(0.0093)	(0.0111)	(0.0090)
R-Squared	0.8332	0.8334	0.8325	0.8335
Lower Middle Income	-0.4727***	-0.4752***	-0.4407***	-0.4765***
	(0.0203)	(0.0204)	(0.0229)	(0.0204)
R-Squared	0.8330	0.8312	0.8333	0.8317
Low Income	-0.9521***	-1.3996***	-1.5867***	-2.2331***
	(0.1349)	(0.1235)	(0.1481)	(0.1221)
R-Squared	0.7644	0.7323	0.8292	0.8430
CE indicators	**European Union-Circular Economy Indicators**			
Renewable energy	-0.1443***	-0.1490***	-0.1033***	-0.1336***
	(0.0128)	(0.0120)	(0.0156)	(0.0120)
R-Squared	0.7020	0.7016	0.7136	0.7103
Muncipal waste generation	0.1192**	0.1202**	0.0972*	0.1201**
	(0.0577)	(0.0580)	(0.0569)	(0.0569)
R-Squared	0.7051	0.7048	0.7157	0.7135
Packaging Waste Recycling	-0.0005	-0.0004	-0.0022**	-0.0021**
	(0.0009)	(0.0009)	(0.0010)	(0.0010)
R-Squared	0.7022	0.7017	0.7172	0.7135
Municipal Waste Recycling	-0.0018*	-0.0018*	-0.0027***	-0.0030***
	(0.0009)	(0.0009)	(0.0009)	(0.0009)
R-Squared	0.7046	0.7043	0.7195	0.7173
Biowaste Waste	-0.0003	-0.0003	-0.0007**	-0.0008***

Recycling				
	(0.0002)	(0.0002)	(0.0002)	(0.0002)
R-Squared	0.7031	0.7028	0.7180	0.7156
Recyclables Trade	-0.026***	-0.021***	-0.0190***	-0.0332***
	(0.0063)	(0.0053)	(0.0049)	(0.0054)
R-Squared	0.7143	0.7129	0.7238	0.7352
Recycling Patents	-0.0001	-0.0002	-0.0003	-0.0006
	(0.0005)	(0.0005)	(0.0005	(0.0005)
R-Squared	0.7020	0.7017	0.7139	0.7113
Abmp	-0.001	-0.001	-0.002***	-0.002***
	(0.0006)	(0.0006)	(0.0006)	(0.0006)
R-Squared	0.7035	0.7031	0.7198	0.7177
AMPWR	-0.0015	-0.0014	-0.0033	-0.0035
	(0.0010)	(0.0010)	(0.0011)	(0.0011)
R-Squared	0.7034	0.7029	0.7198	0.7169
LABTMP	-0.0279***	-0.0217***	-0.0195***	-0.0338***
	(0.0066)	(0.0055)	(0.0051)	(0.0056)
R-Squared	0.7146	0.7128	0.7236	0.7345
Standard errors in parentheses * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$				

Finally, the study also examined the interactive effects of direct and indirect measures of CE. The results reported in table 12 indicate that the emissions effect of municipal waste generation is significantly influenced by recyclable trade. Similarly, the results reported in table 13 suggest that the emissions impact of municipal waste generation is also influenced by recyclables patents. Recycling patents promote carbon neutrality. The interactive term of municipal waste generation and recyclables patents leads to carbon neutrality. Table 14 reports the combined impact of packaging waste recycling with recyclables trade. The interactive impact is negative and significant suggesting that emissions mitigating effect of packing waste recycling is enhanced by recyclable trades. Table 15 presents the combined impact of packaging waste recycling and recycling patents. The interactive term also appears with negative sign, but the coefficient is insignificant. This finding suggest that recycling patents are not enough to consolidate the emissions impact of packing waste recycling.

Table 16 highlights the combined impact of municipal waste recycling and recyclable trade. The interactive term is negative and significant indicating environmental improvement through municipal waste recycling and recyclables trade. Table 17 demonstrates the combined impact of municipal waste recycling and recycling patents. The interactive term is insignificant while municipal waste recycling improves environmental quality through emission reduction. Table 18 reports the combined impact of bio waste recycling and recyclable trade. The interactive term is negative and significant indicating reduction in emission through the implementation of CE measures. Recyclable trade is negative and significant suggesting the contribution of recyclable trade in environmental improvement.

5. Conclusion

The present world is facing growing environmental issues such as increasing waste, excessive extraction of natural resources, deforestation, and loss of biodiversity. These problems are largely attributed to the linear economy, which follows the “take-make-dispose” extractive industrial model. Contrary to this, CE follows the “reduce, reuse, and recycle” circular industrial model. This study investigates renewable energy, CE, and environment nexus by considering renewable energy as a key driver of environmental quality and the main pillar of circular economy practices, including CE indicators. This study covers the time 1990-2014 for global economy as well as for different groups of countries according to their income levels. Furthermore, the study analyzes the influence of various CE measures on carbon emissions of 27 European Union member countries. The results suggest that renewable energy and different measures of CE significantly improve environmental quality. Furthermore, heterogeneous panel techniques that take account of cross-sectional dependence and slope heterogeneity also support our findings that the circular economy contributes to environmental mitigation and helps in achieving sustainable development. Energy intensity, economic growth, and urbanization degrade the environment.

5.1 Contribution of the Study

The sustainable use of resources offers opportunities to combat climate change and global warming. In this regard, renewable resources and CE measures support the global world in the form of reduced waste generation, decreased extraction of resources, and improved production and consumption patterns. The concerns about degrading the environmental quality and climate change have been raised across the world but studies examining the environmental mitigating role of CE indicators are not available. This study is a pioneering study and first of its kind that empirically investigates the influence of renewable energy consumption, an important pillar of CE, on the environmental quality at the global level and in different income groups. Second, the study uses different indicators of the CE like biowaste recycling, municipal waste recycling, the role of patents in recycling, and secondary raw material recycling in enhancing environmental quality in European Union member countries. Third, the study employed 2^{nd} generation tests to analyze the effect of incorporated determinants on environmental quality. Fourth, cointegration among the variable is determined through the Wester-Lund panel co-integration test. Fifth, the study analyzed the long-run relationship among the variables using FMOLS, and DOLS. Sixth, the study also used heterogeneous panel techniques to examine the relationship among the variables which allow slope heterogeneity and cross-sectional dependence.

5.2 Theoretical and Policy Implications

Renewable energy reduces the extraction of fossil fuels, emissions from fossil fuels, waste ending in landfills, water degradation, and climate change. Like the use of renewables, recycling of waste also mitigates environmental degradation as it does not compromise the regenerative capacity of the system and resources are used for a longer period. Biowaste and municipal waste recycling reduce environmental degradation. An increase in the number of patents in recycling and secondary raw material also enhance environmental quality. Thus, our results support the theory of sustainable development as resources are used more efficiently. Furthermore, the findings also suggest the existence of "ecological modernization and eco-industrial development. As economies grow and industrialize, initially, technological backwardness and inefficiency in resource use degrade environmental quality, however with the development, awareness and technological advancement resulting from innovation enhance environmental quality and improve human-environment relationship.

Based on our findings it can be suggested that governments of all economies should promote the circular economy and use of renewable energy as they not only ensure energy security but also shift dependence from finite non-renewable resources to those which can be sustained and are readily available in all the countries regardless of income levels. Renewable energy supports CE as it shifts the reliance from virgin resources to renewable ones whose harnessing does not have an adverse environmental impact. Among different measures of CE, competitiveness and innovations have a more profound impact on environmental quality.

5.3 Study Limitations

The limitations of the study include: First, only 27 EU countries were examined for most of the CE indicators due to the unavailability of data. Second, the study collectively examined the impact of packaging waste recycling and did not examine the disaggregated impacts of individual measures, including the recycling rate of plastic waste, and the recycling rate of wooden packaging. Third, linear analysis is conducted while non-linearities and complex relationships including direct and indirect effects are not explored.

5.4 Future Research Direction

Based on the data availability future studies can examine the impacts of other indicators of CE on environmental sustainability. A comparative analysis can be conducted between the countries practicing CE measures to examine the policies and benefits in terms of reduction in resource consumption and shift to renewable resources. Asymmetries between CE and environmental quality can be examined by future studies, which will help in understanding the complex relationship between different dimensions of CE and their impacts on environmental quality. Furthermore, the robustness of the estimators is not examined in the present study which can be the focal point of future studies.

Grant Support Details / Funding

This research work received no research grant.

REFERENCES

Antikainen, M., Uusitalo, T., & Kivikytö-Reponen, P. (2018). Digitalisation as an enabler of circular economy. *Procedia CIRP, 73*, 45-49.

Argyres, N., & Mayer, K. J. (2007). Contract design as a firm capability: An integration of learning and transaction cost perspectives. *Academy of Management Review, 32*(4), 1060-1077.

Blackburne III, E. F., & Frank, M. W. (2007). Estimation of nonstationary heterogeneous panels. *The Stata Journal*, *7*(2), 197-208.

Bonciu, F. (2014). The European economy: From a linear to a circular economy. *Romanian Journal of European Affairs, 14*(4), 78-91.

Breusch, T. S., Pagan, A. R. (1980). The Lagrange multiplier test and its applications to model specification in econometrics. *The Review of Economic Studies, 47*, 239-253.

Cainelli, G., D'Amato, A., & Mazzanti, M. (2020). Resource efficient eco-innovations for a circular economy: Evidence from EU firms. *Research Policy*, *49*(1), 103827.

Chudik, A., & Pesaran, M. H. (2015). Common correlated effects estimation of heterogeneous dynamic panel data models with weakly exogenous regressors. *Journal of Econometrics, 188*(2), 393-420.

Circle Economy. (2020). *Circularity Gap Report 2020*. Amsterdam: Circle Economy. [ONLINE] Available: https://assets.website-files.com/5e185aa4d27bcf348400ed82/5e26ead616b6d1d157ff4293_20200120%20-%20CGR%20Global%20-%20Report%20web%20single%20page%20-%20210x297mm%20-%20compressed.pdf (November 23rd, 2020).

Cotta, B. (2020). What goes around, comes around? Access and allocation problems in Global North–South waste trade. International Environmental Agreements: *Politics, Law and Economics, 20*(2), 255-269.

Demurtas, A., Sousanoglou, A., Morton, G., Humphris-Bach, A., Essig, C., Harding, L., & Cole, A. (2015). EU Resource Efficiency Scoreboard 2014. *European Commission, Brussels, Belgium*, 1-68.

Deutz, P., & Gibbs, D. (2008). Industrial ecology and regional development: Eco-industrial development as cluster policy. *Regional Studies*, *42*(10), 1313-1328.

Eberhardt, M. (2012). Estimating panel time-series models with heterogeneous slopes. *The Stata Journal, 12*(1), 61-71.

Eberhardt, M., & Bond, S. (2009). Cross-section dependence in nonstationary panel models: A novel estimator. *MPRA*, 1-26.

EC-European Commission. (2015). Closing the loop—An EU action plan for the circular economy. *Communication from the commission to the European parliament, the council, the European economic and social committee and the committee of the regions*, Brussels, Belgium.

Ehigiamusoe, K. U., & Lean, H. H. (2019). Effects of energy consumption, economic growth, and financial development on carbon emissions: Evidence from heterogeneous income groups. *Environmental Science and Pollution Research*, *26*(22), 22611-22624.

Eisenhardt, K. M. (1989). Agency theory: An assessment and review. *Academy of Management Review*, *14*(1), 57-74.

Ekins, P., Domenech, T., Drummond, P., Bleischwitz, R., Hughes, N., & Lotti, L. (2019). The Circular Economy: What, Why, How and Where. *Background paper for an OECD/EC Workshop on 5 July 2019 within the workshop series. Managing environmental and energy transitions for regions and cities*, *5*, 1-82.

Elia, V., Gnoni, M. G., & Tornese, F. (2017). Measuring circular economy strategies through index methods: A critical analysis. *Journal of Cleaner Production, 142*, 2741-2751.

Ellen MacArthur Foundation, & McKinsey Center for Business and Environment. (2015). *Growth within: A circular economy vision for a competitive Europe*. Ellen MacArthur Foundation. [ONLINE] Available: https://www.ellenmacarthurfoundation.org/publications/growth-within-a-circular-economy-vision-for-a-competitive-europe (September 19th, 2020).

Ellen MacArthur Foundation. (2013). Towards the circular economy. *Journal of Industrial Ecology*, *2*, 23-44.

Ellen MacArthur Foundation. (2014). *Towards the circular economy: Economic and business rationale for an accelerated transition*. [ONLINE] Available: https://www.werktrends.nl/app/uploads/2015/06/Rapport_McKinsey-owards_A_Circular_Economy.pdf (October 17th, 2020).

Ellen MacArthur Foundation. (2015). Delivering *the circular economy - a toolkit for policy makers*. Ellen MacArthur Foundation. [ONLINE] Available: https://www.ellenmacarthurfoundation.org/assets/downloads/publications/EllenMacArthurFoundation_PolicymakerToolkit.pdf (October 17th, 2020).

Ellen MacArthur Foundation. (2019). *Completing the picture: How the circular economy tackles climate change*. [ONLINE] Available: www.ellenmacarthurfoundation.org/publications (October 17th, 2020).

European Commission. (2018). *Measuring progress toward circular economy in the European Union – Key indicators for a monitoring framework*. Strasbourg, 16.1.2018, SWD (2018) 17 final.

Eurostat (2020). Circular Economy Indicators. European Commission: Brussels. [ONLINE] Available: https://ec.europa.eu/eurostat/web/circular-economy/indicators (November 5th, 2020).

FAO. (2016). *Scoping study on decent work and employment in fisheries and aquaculture: Issues and actions for discussion and programming*. Food and Agriculture Organization, United Nations.

Grossman, G. M., & Krueger, A. B. (1995). Economic growth and the environment. *The Quarterly Journal of Economics, 110*(2), 353-377.

Harris, S., & Rydberg, T. (2018). *Renewable Materials in the Circular Economy. (No* C296*).* IVL Swedish Environmental Research Institute, Sweden.

Haupt, M., & Hellweg, S. (2019). Measuring the environmental sustainability of a circular economy. *Environmental and Sustainability Indicators, 1*, 100005-100011.

Heyes, G., Sharmina, M., Mendoza, J. M. F., Gallego-Schmid, A., & Azapagic, A. (2018). Developing and implementing circular economy business models in service-oriented technology companies. *Journal of Cleaner Production*, *177*, 621-632.

IPCC, (2019). Summary for Policymakers. *Climate Change and Land: IPCC Special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems*. Cambridge University Press, Cambridge, United Kingdom and New York.

IRENA. (2019). *Global energy transformation: A roadmap to 2050 (2019 edition)*. International Renewable Energy Agency, Abu Dhabi.

IRP. (2017). *Assessing global resource use: A systems approach to resource efficiency and pollution reduction*. A Report of the International Resource Panel. United Nations Environment Programme. Nairobi, Kenya.

Kao, C. (1999). Spurious regression and residual-based tests for cointegration in panel data. *Journal of Econometrics*, *90*(1), 1-44.

Khan, S., & Majeed, M. T. (2020). Drivers of decoupling economic growth from carbon emission: Empirical analysis of ASEAN countries using decoupling and decomposition model. *Pakistan Journal of Commerce and Social Sciences*, *14*(2), 450-483.

Korhonen, J., Honkasalo, A., & Seppala, J. (2018). Circular economy: The concept and its limitations. *Ecological Economics, 143*, 37-46.

Korhonen, J., Nuur, C., Feldmann, A., & Birkie, S. E. (2018). Circular economy as an essentially contested concept. *Journal of Cleaner Production, 175*, 544-552.

Kravchenko, M., McAloone, T. C., & Pigosso, D. C. (2020). To what extent do circular economy indicators capture sustainability? *Procedia CIRP*, *90*, 31-36.

Lahti, T., Wincent, J., & Parida, V. (2018). A definition and theoretical review of the circular economy, value creation, and sustainable business models: where are we now and where should research move in the future? *Sustainability, 10*(8), 1-19.

Lv, Z., & Xu, T. (2018). Is economic globalization good or bad for the environmental quality? New evidence from dynamic heterogeneous panel models. *Technological Forecasting and Social Change, 137*, 340-343.

Magazzino, C., Mele, M., & Schneider, N. (2020). The relationship between municipal solid waste and greenhouse gas emissions: Evidence from Switzerland. *Waste Management, 113,* 508–520.

Magnier, C. (2017). 10 key indicators for monitoring the circular economy: 2017 Edition. *France, General Commission for Sustainable Development.*

Majeed, M. T. (2018). Information and communication technology (ICT) and environmental sustainability in developed and developing countries. *Pakistan Journal of Commerce and Social Sciences*, *12*(3), 758-783.

Majeed, M. T., & Luni, T. (2019). Renewable energy, water, and environmental degradation: A global panel data approach. *Pakistan Journal of Commerce and Social Sciences (PJCSS)*, *13*(3), 749-778.

Majeed, M. T., & Mazhar, M. (2019). Environmental degradation and output volatility: A global perspective. *Pakistan Journal of Commerce and Social Sciences, 13*(1), 180-208.

Majeed, M. T., & Mazhar, M. (2019). Financial development and ecological footprint: A global panel data analysis. *Pakistan Journal of Commerce and Social Sciences (PJCSS), 13*(2), 487-514.

Majeed, M. T., & Mazhar, M. (2020). Reexamination of Environmental Kuznets Curve for Ecological Footprint: The Role of Biocapacity, Human Capital, and Trade. *Pakistan Journal of Commerce and Social Sciences, 14*(1), 202-254.

Majeed, M. T., & Tauqir, A. (2020). Effects of urbanization, industrialization, economic growth, energy consumption, financial development on carbon emissions: An extended STIRPAT model for heterogeneous income groups. *Pakistan Journal of Commerce and Social Sciences (PJCSS)*, *14*(3), 652-681.

Material Economics. (2018). The circular economy: A powerful tool for climate mitigation, Material Economics. [ONLINE] Available: https://media.sitra.fi/2018/06/12132041/the-circular-economy-a-powerful-force-for-climate-mitigation.pdf (June 14th, 2020).

Millar, N., McLaughlin, E., & Börger, T. (2019). The circular economy: Swings and roundabouts? *Ecological Economics, 158*, 11-19.

Moraga, G., Huysveld, S., Mathieux, F., Blengini, G. A., Alaerts, L., Van Acker, K., & Dewulf, J. (2019). Circular economy indicators: What do they measure? *Resources, Conservation and Recycling, 146, 452-461.*

Murray, A., Skene, K., & Haynes, K. (2017). The circular economy: An interdisciplinary exploration of the concept and application in a global context. *Journal of Business Ethics*, *140*(3), 369-380.

Pedroni, P. (1999). Critical values for cointegration tests in heterogeneous panels with multiple regressors. *Oxford Bulletin of Economics and Statistics*, *61*(S1), 653-670.

Pedroni, P. (2001). Fully modified OLS for heterogeneous cointegrated panels. In nonstationary panels, panel cointegration, and dynamic panels (pp. 93-130). Emerald Group Publishing Limited.

Pesaran, M. H. (2004). *General diagnostic tests for cross section dependence in panels (*No. 1229). CESIFO; University of Cambridge, UK.

Pesaran, M. H. (2006). Estimation and inference in large heterogeneous panels with a multifactor error structure. *Econometrica*, *74*(4), 967-1012.

Pesaran, M. H. (2007). A simple panel unit root test in the presence of cross-section dependence. *Journal of Applied Econometrics*, *22*(2), 265-312.

Pesaran, M. H., & Smith, R. (1995). Estimating long-run relationships from dynamic heterogeneous panels. *Journal of Econometrics, 68*(1), 79-113.

Pesaran, M. H., Ullah, A., & Yamagata, T. (2008). A bias-adjusted LM test of error cross-section independence. *The Econometrics Journal*, *11*(1), 105-127.

Rincón-Moreno, J., Ormazábal, M., Álvarez, M. J., & Jaca, C. (2020). Advancing circular economy performance indicators and their application in Spanish companies. *Journal of Cleaner Production*, *279*, 123605 (1-10).

Samreen, I., & Majeed, M. T. (2020). Spatial econometric model of the spillover effects of financial development on carbon emissions: A global analysis. *Pakistan Journal of Commerce and Social Sciences*, *14*(2), 569-202.

Schroder, P. (2020). Promoting a just transition to an inclusive circular economy. Energy, Environment and Resource Program. *Catham House*, 1-33.

Schroeder, P., Anggraeni, K., & Weber, U. (2019). The relevance of circular economy practices to the sustainable development goals. *Journal of Industrial Ecology*, *23*(1), 77-95.

Shafiei, S., & Salim, R. A. (2014). Non-renewable and renewable energy consumption and CO_2 emissions in OECD countries: A comparative analysis. *Energy Policy*, *66*, 547-556.

Sirmon, D. G., Hitt, M. A., & Ireland, R. D. (2007). Managing firm resources in dynamic environments to create value: Looking inside the black box. *Academy of Management Review*, *32*(1), 273-292.

Stahel, W., & Reday, G. (1976). *The Potential for Substituting Manpower for Energy*. Report the Commission of the European Communities, Battelle, Geneva Research Centre, Brussels.

Stahel,W. (1982). The product life factor. In: Orr, G.S. (Ed.), An Inquiry into the Nature of Sustainable Societies. The Role of the Private Sector. Houston Area Research Centre, Houston, pp. 72e105.

Stock, J. H., & Watson, M. W. (1993). A simple estimator of cointegrating vectors in higher order integrated systems. *Econometrica: Journal of the Econometric Society*, *61*(4), 783-820.

Suarez-Eiroa, B., Fernandez, E., Méndez-Martinez, G., & Soto-Oñate, D. (2019). Operational principles of circular economy for sustainable development: Linking theory and practice. *Journal of Cleaner Production*, *214*, 952-961.

Tunn, V. S. C., Bocken, N. M. P., van den Hende, E. A., & Schoormans, J. P. L. (2019). Business models for sustainable consumption in the circular economy: An expert study. *Journal of Cleaner Production*, *212*, 324-333.

UN General Assembly, (2015). *Transforming our world: The 2030 Agenda for Sustainable Development.* [ONLINE] Available: https://www.refworld.org/docid/57b6e3e44.html (November 5th, 2020).

UN DESA. (2020). *World Social Report 2020, Inequality in a rapidly changing world*. UN Department of Economic and Social Affairs, Geneva: United Nations.

Westerlund, J., & Edgerton, D. L. (2007). A panel bootstrap cointegration test. *Economic Letters*, *97*, 185–190.

World Bank. (2020). World development indicators. World Bank: Washington DC.

Appendix

Table 12: Results of Municipal Waste Generation and Recyclables Trade

	Dependent Variable: lCO_2				
Variables	**Combined effects of CE measures**				
	Equation (5.1a)				
	(1)	(2)	(3)	(4)	(5)
GDP per capita	1.019^{***}	1.007^{***}	1.008^{***}	0.994^{***}	0.959^{***}
	(0.0366)	(0.0365)	(0.0366)	(0.0367)	(0.0382)
Renewable Energy per capita	-0.134^{***}	-0.124^{***}	-0.125^{***}	-0.121^{***}	-0.119^{***}
	(0.0121)	(0.0125)	(0.0124)	(0.0124)	(0.0123)
Energy intensity per capita	0.963^{***}	0.999^{***}	1.001^{***}	0.994^{***}	0.929^{***}
	(0.0448)	(0.0466)	(0.0467)	(0.0450)	(0.0497)
Urbanization	-0.424^{***}	-0.449^{***}	-0.452^{***}	-0.447^{***}	-0.398^{***}
	(0.0806)	(0.0806)	(0.0806)	(0.0796)	(0.0806)
lGMRT*LRT	-0.00262^{***}		-0.00297^{***}	0.016^{***}	0.0807^{***}
	(0.000800)		(0.000805)	(0.0053)	(0.0221)
lGMW		0.123^{**}	0.154^{***}		-0.699^{***}
		(0.0568)	(0.0576)		(0.232)
lRT		-0.0194^{***}		-0.121^{***}	-0.528^{***}
		(0.00507)		(0.0343)	(0.139)
Constant	-3.597^{***}	-4.085^{***}	-4.271^{***}	-3.201^{***}	1.198
	(0.306)	(0.383)	(0.396)	(0.3223)	(1.494)
Observations	405	405	405	405	405
R-squared	0.709	0.715	0.714	0.718	0.724
Adjusted R-squared	0.706	0.711	0.710	0.713	0.720
"Standard errors in parentheses; Probabilities represented by * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$"					

Table 13: Results of Municipal waste generation and Recycling Patents

Variables	**Dependent Variable: lCO_2**				
	Combined effects of CE measures				
	Equation (5.1b)				
	(1)	(2)	(3)	(4)	(5)
GDP per capita	1.005^{***}	0.995^{***}	0.995^{***}	1.005^{***}	0.990^{***}
	(0.0370)	(0.0371)	(0.0371)	(0.0369)	(0.0369)
Renewable Energy per capita	-0.149^{***}	-0.144^{***}	-0.144^{***}	-0.149^{***}	-0.141^{***}
	(0.0114)	(0.0116)	(0.0116)	(0.0113)	(0.0115)
Energy intensity per capita	0.968^{***}	0.998^{***}	0.999^{***}	0.961^{***}	1.003^{***}
	(0.0454)	(0.0475)	(0.0475)	(0.0456)	(0.0471)
Urbanization	-0.463^{***}	-0.488^{***}	-0.488^{***}	-0.463^{***}	-0.504^{***}
	(0.0807)	(0.0814)	(0.0813)	(0.0806)	(0.0809)
lGMW*RP	-0.00004		-0.00005	-0.0044	-0.0086^{***}
	(0.0001)		(0.0001)	(0.0029)	(0.0031)
lGMW		0.120^{**}	0.120^{**}		0.193^{***}
		(0.0578)	(0.0578)		(0.0635)
RP		-0.0002		0.0279	0.0541^{***}
		(0.0005)		(0.0184)	(0.0202)
Constant	-3.373^{***}	-3.874^{***}	-3.879^{***}	-3.393^{***}	-3.201^{***}
	(0.304)	(0.383)	(0.389)	(0.304)	(0.407)
Observations	405	405	405	405	405
R-squared	0.702	0.705	0.705	0.703	0.710
Adjusted R-squared	0.698	0.700	0.700	0.699	0.705
"Standard errors in parentheses; Probabilities represented by * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$"					

Table 14: Results of Packaging waste recycling and Recyclables trade

Variables	**Dependent Variable: lCO_2**				
	Combined effects of CE measures				
	Equation (5.2a)				
	(1)	(2)	(3)	(4)	(5)
GDP per capita	1.030^{***}	1.014^{***}	1.013^{***}	1.026^{***}	1.003^{***}
	(0.0370)	(0.0373)	(0.0366)	(0.0370)	(0.0362)
Renewable Energy per capita	-0.129^{***}	-0.131^{***}	-0.133^{***}	-0.126^{***}	-0.148^{***}
	(0.0125)	(0.0129)	(0.0123)	(0.0126)	(0.0130)
Energy intensity per capita	0.967^{***}	0.967^{***}	0.952^{***}	0.967^{***}	0.9283^{***}
	(0.0447)	(0.0447)	(0.0441)	(0.0446)	(0.0440)
Urbanization	-0.405^{***}	-0.425^{***}	-0.378^{***}	-0.407^{***}	-0.329^{***}
	(0.0812)	(0.0804)	(0.0800)	(0.0810)	(0.0803)
PWR*lRT	-0.0002^{***}		-0.0005^{***}	-0.0001	-0.0014^{***}
	(0.0001)		(0.0001)	(0.0001)	(0.0002)
PWR		0.0003	0.006^{***}		0.0149^{***}
		(0.0001)	(0.0015)		(0.0030)
lRT		-0.0195^{***}		-0.0127^{*}	0.0484^{***}
		(0.0052)		(0.0072)	(0.0143)
Constant	-3.859^{***}	-3.540^{***}	-3.943^{***}	-3.747^{***}	-4.493^{***}
	(0.329)	(0.315)	(0.324)	(0.334)	(0.358)
Observations	405	405	405	405	405
R-squared	0.711	0.712	0.722	0.713	0.730
Adjusted R-squared	0.707	0.708	0.717	0.709	0.725
“Standard errors in parentheses; Probabilities represented by * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$”					

Table 15: Results of Packaging Waste Recycling and Recycling Patent

Variables	**Dependent Variable: lCO_2**				
	Combined effects of CE measures				
	Equation (5.2b)				
	(1)	(2)	(3)	(4)	(5)
GDP per capita	1.004^{***}	1.007^{***}	1.007^{***}	1.005^{***}	1.010^{***}
	(0.0370)	(0.0379)	(0.0379)	(0.0370)	(0.0381)
Renewable Energy per capita	-0.149^{***}	-0.147^{***}	-0.147^{***}	-0.149^{***}	-0.145^{***}
	(0.0114)	(0.0126)	(0.0126)	(0.0114)	(0.0127)
Energy intensity per capita	0.968^{***}	0.969^{***}	0.969^{***}	0.970^{***}	0.971^{***}
	(0.0454)	(0.0455)	(0.0455)	(0.0454)	(0.0455)
Urbanization	-0.463^{***}	-0.460^{***}	-0.460^{***}	-0.465^{***}	-0.461^{***}
	(0.0808)	(0.0813)	(0.0813)	(0.0809)	(0.0813)
PWR*RP	-0.000002		-0.000001	-0.00004	-0.00005
	(0.000007)		(0.00001)	(0.00005)	(0.00001)
PWR		-0.0003	-0.0004		0.0006
		(0.0001)	(0.0010)		(0.0010)
RP		-0.0002		-0.0029	-0.0036
		(0.0005)		(0.0037)	(0.0038)
Constant	-3.367^{***}	-3.403^{***}	-3.400^{***}	-3.359^{***}	-3.416^{***}
	(0.305)	(0.319)	(0.319)	(0.305)	(0.319)
Observations	405	405	405	405	405
R-squared	0.702	0.702	0.702	0.7032	0.702
Adjusted R-squared	0.698	0.697	0.697	0.698	0.697
"Standard errors in parentheses; Probabilities represented by * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$"					

Table 16: Results of Municipal Waste Recycling and Recyclables Trade

Variables	**Dependent Variable: lCO_2**				
	Combined effects of CE measures				
	Equation (5.3a)				
	(1)	(2)	(3)	(4)	(5)
GDP per capita	1.057**	1.028***	0.998***	1.043***	0.995***
	(0.0397)	(0.0410)	(0.0405)	(0.0400)	(0.0405)
Renewable Energy per capita	-0.137***	-0.129***	-0.137***	-0.128***	-0.143***
	(0.0118)	(0.0124)	(0.0114)	(0.0123)	(0.0124)
Energy intensity per capita	0.981***	0.971***	0.955***	0.975***	0.953***
	(0.0449)	(0.0450)	(0.0401)	(0.0448)	(0.0440)
Urbanization	-0.403***	-0.416***	-0.369***	-0.400***	-0.363***
	(0.0816)	(0.0811)	(0.0797)	(0.0812)	(0.0797)
MWR*RT	-0.0002***		-0.0013***	-0.0001	-0.0017***
	(0.0001)		(0.0002)	(0.0001)	(0.0003)
MWR		-0.0006	0.0167***		0.0205***
		(0.0010)	(0.0034)		(0.0045)
lRT		-0.0180***		-0.0140**	0.0101
		(0.0055)		(0.0060)	(0.0143)
Constant	-4.134***	-3.701***	-3.812***	-3.941***	-3.877***
	(0.377)	(0.384)	(0.373)	(0.385)	(0.376)
Observations	405	405	405	405	405
R-squared	0.710	0.712	0.726	0.714	0.727
Adjusted R-squared	0.706	0.708	0.722	0.709	0.723
"Standard errors in parentheses; Probabilities represented by * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$"					

Table 17: Results of Municipal Waste Recycling and Recycling Patents

Variables	**Dependent Variable: lCO_2**				
	Combined effects of CE measures				
	Equation (5.3b)				
	(1)	(2)	(3)	(4)	(5)
GDP per capita	1.003^{***}	1.042^{***}	1.046^{***}	1.004^{***}	1.054^{***}
	(0.0370)	(0.0417)	(0.0419)	(0.0370)	(0.0421)
Renewable Energy per capita	-0.149^{***}	-0.141^{***}	-0.140^{***}	-0.149^{***}	-0.139^{***}
	(0.0114)	(0.0120)	(0.0120)	(0.0114)	(0.0120)
Energy intensity per capita	0.968^{***}	0.979^{***}	0.981^{***}	0.970^{***}	0.985^{***}
	(0.0454)	(0.0456)	(0.0456)	(0.0454)	(0.0456)
Urbanization	-0.463^{***}	-0.460^{***}	-0.460^{***}	-0.465^{***}	-0.461^{***}
	(0.0808)	(0.0813)	(0.0813)	(0.0809)	(0.0813)
MWR*RP	-0.000001		0.00001	0.00003	0.000006^{*}
	(0.000009)		(0.00001)	(0.00003)	(0.00003)
MWR		-0.0021^{*}	-0.0024^{**}		-0.0027^{**}
		(0.0011)	(0.0011)		(0.0011)
RP		-0.0003		-0.0021	-0.0030
		(0.0005)		(0.0019)	(0.0019)
Constant	-3.358^{***}	-3.857^{***}	-3.915^{***}	-3.361^{***}	-3.994^{***}
	(0.305)	(0.394)	(0.398)	(0.305)	(0.401)
Observations	405	405	405	405	405
R-squared	0.702	0.704	0.705	0.702	0.707
Adjusted R-squared	0.698	0.700	0.701	0.698	0.702

"Standard errors in parentheses; Probabilities represented by * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$"

Table 18: Results of Bio waste recycling and Recyclables Trade

Variables	**Dependent Variable: lCO_2**				
	Combined effects of CE measures				
	Equation (5.4a)				
	(1)	(2)	(3)	(4)	(5)
GDP per capita	1.030***	1.018***	1.006***	1.022***	1.009***
	(0.0393)	(0.0393)	(0.0396)	(0.0389)	(0.0395)
Renewable Energy per capita	-0.146***	-0.130***	-0.141***	-0.130***	-0.132***
	(0.0114)	(0.0123)	(0.0114)	(0.0123)	(0.0123)
Energy intensity per capita	0.971***	0.968***	0.959***	0.968***	0.962***
	(0.0452)	(0.0447)	(0.0449)	(0.0447)	(0.0448)
Urbanization	-0.403***	-0.416***	-0.369***	-0.400***	-0.363***
	(0.0816)	(0.0811)	(0.0797)	(0.0812)	(0.0797)
BWR*lRT	-0.00004*		-0.0004***	-0.00001	-0.0002*
	(0.00002)		(0.0001)	(0.00002)	(0.0001)
BWR		-0.00001	0.0048***		0.003*
		(0.0003)	(0.0015)		(0.0018)
lRT		-0.0191***		-0.0184***	-0.0121*
		(0.0054)		(0.0056)	(0.0067)
Constant	-3.662***	-3.576***	-3.578***	-3.618***	-3.580***
	(0.341)	(0.338)	(0.338)	(0.337)	(0.337)
Observations	405	405	405	405	405
R-squared	0.704	0.712	0.712	0.712	0.714
Adjusted R-squared	0.701	0.707	0.707	0.708	0.709
"Standard errors in parentheses; Probabilities represented by * p < 0.1, ** p < 0.05, *** p < 0.01"					