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Abstract

This study contributes to estimate the municipal solid waste (MSW) recycling effect on environmental quality and economic growth in the United States. Few studies have been given to macro-level aggregate analysis through national scale MSW recycling, environmental, and economic indicators. This study employs bootstrapping autoregressive distributed lag modeling for investigating the cointegration relationship among MSW recycling, economic growth, carbon emissions, and energy efficiency utilized quarterly data from 1990 to 2017. The result implies that a one percent increase in MSW recycling contributes to economic growth and reduce carbon emissions by 0.317% (0.157%) and 0.209% (0.087%) in the long-run (short-run). Similarly, a one percent improvement in energy efficiency stimulates economic growth by 0.489% (0.281%) and mitigates carbon emissions by 0.285% (0.197%) in the long-run (short-run). A higher per capita income and population growth caused higher emissions by 0.197% and 0.401% in the long-run. The overall results reveal stronger impacts in the long-run than the short-run with significant convergence towards long-run equilibrium, suggesting a prominent long-run transmission of economic and environmental fallouts. This study confirms a uni-directional causality from MSW recycling to economic growth, carbon emissions, and energy efficiency. These outcomes signify that any policy intervention related to MSW recycling produces significant changes in the level of economic growth and carbon emissions. The finding provides valuable insight for policymakers to counteract carbon emissions through recyclable waste management that simultaneously create significant economic value.

Keywords: Municipal Solid Waste Recycling; Carbon emissions; Energy efficiency; Economic growth; Bootstrapping autoregressive distributed lag

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1. Introduction

Today's world isfacing various challenges of overpopulation, industrial development, urbanization, and climate change that urge policymakers to devise sustainable and practical solutions on a war footing basis (Philippidis et al., 2019). These mounting factors lead to higher consumption and subsequent generation of abnormal waste, which continuously putting pressure on natural resources and environmental sustainability. Also, the adverse effect of waste on living creatures, socio-economic dynamics, and climate change further complicates its remedial process (Jeng et al., 2020; Gardiner and Hajek, 2020; Uddin et al., 2017). Amid raising these concerns, waste management is becoming a global issue, and circular economy practices is considered an instrument to achieve sustainable growth. Potting et al. (2017) presented a circular design based on 9R principles, where different production chains are categorized based on Refuse, Rethink, Reduce, Reuse, Repair, Refurbish, Remanufacturing, Repurpose, Recycling, and Recover. These CE principles are chronologically arranged from a circular economy to a linear economy. Kirchherr et al. (2017) exhibited that the prior definitions of CE are mainly focused to reduce, reuse and recycling activities, while systematic shift of CE is often neglected. Based on the various definitions of CE, Kirchherr et al. (2017) concluded that the prime objective of CE is to achieve economic progression, followed by environmental conservation and its societal impact.

Conferring to World Bank report (World Bank, 2019) 'Waste 2.0', the world generates 2.01 billion tons of municipal solid waste (MSW) that is expected to grow to 3.4 billion tons by 2050. This growth is projected to be more pronounced in low-middle income countries by 40 percent, followed by high-income countries by 19 percent or more (Kaza et al., 2018). Notably, 67 percent of total MSW disposed through the conventional and unsustainable process, e.g., landfilling, open dumping, and combustion that attributes to 1.6 billion tonnes of carbon emissions (Karak et al., 2012). MSW management cost is expected to surge from 205 billion USD to 376 billion by 2025 (Hoornweg and Bhada-Tata, 2012). The poor management of global MSW is also attributed to lack of sequester infrastructure and appropriate measures in terms of governance and environmental policing. Recently, Maalouf et al. (2020) estimated the delivered capacity of newly build waste-related infrastructure projects worldwide. From 2014 to 2019, these facilities delivered amounted to 243 million metric tons (Mt), out of which 45% was only delivered in developed economies, 37.5% in China, and only 17.5% in the rest of the world, primarily through thermal treatment (57%) and landfilling (8%). The concentration ratio of newly builds MSW infrastructure facilities is higher in the developed world; United States (US) and China are together accounted for 50% of total delivery, leaving a continual rise in uncontrolled disposal due to the prevailing gap between the actual changes in MSW generation and current MSW infrastructure delivery.

The global waste statistics disclose that US is the largest contributor of municipal solid waste across the world that produces 12 percent of global municipal waste and representing only 4 percent of the global population. In contrast, India and China generate 27 percent of global waste and carries 36 percent of the global population (Wrold Bank, 2019). For these reasons, the waste management framework is firmly legitimized in the US by the “Resource Conservation and Recovery Act” conceded in 1976, which aims to manage waste collection and disposal sustainably. Achieving economic growth and sustainable development is the core Resource Conservation and Recovery Act agenda through the reduction of ecological footprint (Gaba, 2001). Similar directions are guided by sustainable development goals formalized by the United Nations, where sustainable development is linked with sustainable development goal-12 “responsible consumption and production”, and target 12.4 makes obvious reference to “achieve the environmentally sound management of chemicals and all wastes throughout their life cycle" (UN 2020). In this context, hazardous waste disposal and pollutants are critical targets to realize these sustainable development goals in the effective management of common natural resources. Encouraging businesses, industries, and communities to reduce and recycle waste is imperative, as it leads towards sustainable consumption patterns by 2030.

Recovering and reprocessing by means of *recycling* is an organic measure by which the maximum consumption of the resources is attained with the least possible additional cost to the environment (Ayodele et al., 2018; Tseng et al., 2020; Tsai et a., 2020). Countries have urged to reform and channelize the waste for recycling by which the sustainability between resources and the environment is maintained (Xing et al., 2020). Recycling protects natural bio networks, preserves natural resources, and promotes bio-diversity to improve the long-term sustainability of the global eco-system (Ayodele et al., 2018; Robaina et al., 2020). Recycling eliminates noxious wastes, and ecological pollution certainly produces beneficial effects for human health and other living creatures (Jabbour et al., 2019). Especially, MSW recycling has the potential to be a vital strategy for long-term sustainability and improves the productivity and health of the natural eco-system (Ranta and Saari, 2019; Das et al., 2019).

Conceptually, waste is energy that has been converted but not utilizes in the course of doing something valuable (Badgett and Milbrandt, 2020). Interestingly toxic waste is negative energy, as it required further energy to mitigate the adverse impacts of air and water pollution (Balayannis, 2020). Entropy is unavoidable, but waste is not, and recycling decreases wasted energy in the system (Philippidis et al., 2019). Recycling helps to protect the biosphere and sustain humanity by reducing atmospheric carbon measured through LCA (Khandelwal et al., 2019). The recent threat of climate change is attributed to the accumulation of carbon emissions from energy and fossil fuel consumption (Acheampong, 2018). This can efficiently deal with recycling, where paper and other forest product recycling conserves forests, and biological waste recycling restores the organic matter of soil. Together, material recycling efficiently reduces the net carbon emissions, raises carbon sequestration in soil and forest, and serves as a catalyst to balance the energy loss to entropy (Xu et al., 2017).

Apart from ecological benefits, recycling services and materials that are traded in the market significantly contribute to economic activity (Gardiner and Hajek, 2020). Recycling activities are preferred for industries as it has lower economic costs than economic benefits that decrease firms financial cost and operational inefficiencies (Franchetti, 2009; Rehman Khan and Yu, 2020). The recycling practices in industries and logistic operations are guided by the circular economy principles, where a sustainable process has been adopted to reduce waste through a green supply chain (Green et al., 2012; Tsai et a., 2020). Prior studies echoed the financial benefits that emerge from adopting recycling and remanufacturing practices in different industries (Khan and Qianli, 2017; Rosa et al., 2020).

According to REI (2016), material recycling in the US creates 0.757 million jobs, generates 36.6 billion wages, and collect 6.7 billion tax revenues. It indicates that material recycling generates 1.6 jobs for processing of every 1,000 tons of materials (Park et al., 2015). In the US, solid waste management industry's earnings jump from 39.4 billion dollars to 63.4 billion dollars between 2000 to 2017, shows an exponential growth of 61 percent. This industry mainly covers activities related to collection, transportation, transfer stations, disposal, landfill ownership, and management of solid waste and recyclables (ST,2020). The total revenue collected by the US remanufacturing and recycling firms is estimated to be more than USD 280 billion, which comprises 8.9% of their total sales in 2015 (Wu et al., 2018). These positive economic and environmental fallouts of MSW recycling pave the way towards sustainable development. Many studies highlighted that waste recycling in the supply chain process (Jafari et al., 2017), food waste (Omolayo et al., 2021), and material recycling in urban development (Obeng-Odoom, 2014) play an imperative role to achieve sustainable development. Although recycling industry in the US has shown an increasing trend in both ecological and economic aspects, yet it is far behind their maximum potentials (Lonca et al., 2020).

Despite unremitting benefits and sequester measures in terms of legislation and public awareness, and penalties, the generation of municipal solid wastes (MSW) in the US continues to grow and reach 267.8 million tons, out of which 94 million tons were recycled (EPA, 2020a). Figure 1a visualizes the generation of total municipal solid waste (million tons) that comprises; paper and paperboards, yard trimming, metals, plastic, amongst others. Paper and paperboard recycling process about 44.2 million tons of MSW, resulted in the largest portion of the total MSW reduction of about 148 million metric tons (MMT) of carbon emissions in 2017. This reduction is equivalent to removing over 31 million cars from the road for one year (EPA, 2020a). Figure 1b shows the disposal of total wastes in terms of recycling, composting, combustion (burning), and landfill[1]. Although 75% of US waste is recyclable, but the relative share of recycling is still 35% of total municipal waste, which is far less than the conventional waste management tool such as landfilling that accounts for 53% of total waste (EPA,2020a). The disposal of landfills implies a loss of economic value of waste (World Bank, 2018) and causes a substantial volume of carbon emissions and methane (Maria et al., 2020). The situation of waste management is getting worse after China's ban on plastic waste imports from US in January 2018, which creates waste surplus in US and shortage in China driven by their higher domestic consumption. This deficit can only be adjusted by increasing the domestic recycling capacity of China, EU, and US. Currently, US is relocating their waste to south Asian countries by simultaneously taking policy measures such as "plastic restriction" in US states San Francisco and Seattle. Being largest exporter of Waste, EU countries are also taking steps to minimize single-use plastics and non-recycled plastic (Huang et al., 2020; Wang et al., 2019).

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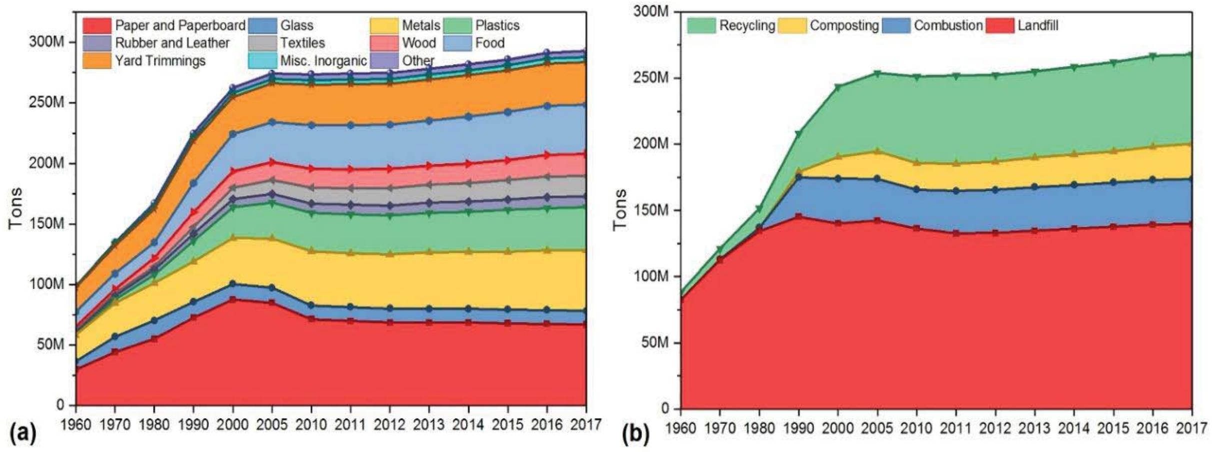
[1] Recycling is a series of activities that includes collecting used, reused, or unused items that would otherwise be considered waste; sorting and processing the recyclable products into raw materials; and remanufacturing the recycled raw materials into new products. Consumers provide the last link in recycling by purchasing products made from recycled content. Composting is also the part of recycling in which organic waste (i.e kitchen waste, and yard trimming waste etc.) is decompose to produce fertilizer. In this paper, the term recycling means recycling plus composting

Figure 1: US MSW Generation (by Source) **US MSW Management (Treatments)**



Source: Author’s drawing from EPA (2020a) data set (y-axis shows figures in Million Tons and x-axis reports year)

As an alternative measure, European Union (EU) members and China intends to deepen its efforts to achieve a circular economy (CE), which is motivated by the reduction of total impact on resource use to make production process efficient (McDowall et al., 2017). In doing so, EU countries proposed to restrain landfilling maximum by 10% of municipal waste and increase MSW recycling target from 50% to 65% of total MSW by 2030. Similar efforts are underway in Japan, where significant attention has been given to increase MSW recycling and reduce incineration ratio because currently 80% of country’s waste is incinerated in more than eleven hundred incinerators (World Bank, 2018). Apart from the common objective of resource efficiency, CE practices in EU are different in China. Chinese perspective of CE is broad, which is framed to mainly tackle environmental pollution that emerged from rapid industrialization and growth. Unlike China, EU has n a narrower environmental scope, concentrating on resources, waste, and respective business opportunities (McDowall et al., 2017). Another study highlighted that lack of regularity pressure, lack of environmental education, and culture are the main barriers to achieving CE in China (Zhang et al., 2019).

Interestingly, if recycling capacity would increase up to the maximum level, it has an impact of reducing emissions equal to 50 Million cars on US roads. Currently, recycling, composting, combustion with energy recovery, and MSW's landfilling saved over 184 MMT of carbon emissions equivalent. This is comparable to the emissions that could be reduced from taking over 39 million cars off the road in a year (EPA, 2020b). According to EPA (2020b) estimates, land filing, wastewater treatment, and composting produced greenhouse gasses (GHGs) emissions equivalent to 110.56 MMT (82.2 % of total waste), 19.22 MMT (14.3 % of total waste), and 4.66 MMT (3.5 % of total waste) of carbon dioxide, while overall municipal waste caused 4 % of the total US emissions of anthropogenic GHGs (Psomopoulos et al., 2009). Figure 1b highlighted mixed methods of MSW treatment lead by landfilling and recycling. Both of the treatments produced dissimilar eco-environmental effects. Therefore, it is imperative to estimate the net emissions reduction/growing effect of MSW *Recycling* in US at the national scale, which can help us to affirm that either *Recycling* practices in US are sustainable or not and what is the economic impact of recycling process. Both questions set out the foundation to achieve sustainable development in the long-term.

There is a dearth of empirical evidence to draw a link between material recycling and carbon emissions at the national level. Moreover, the economic impact of material recycling at the country level is missing in the US. The prevailing studies on recycling are limited to firm, industry, community, or survey level analysis that discussed the scientific procedures, products, and their relative efficiency (Li et al., 2018). A few studies draw causal links between economic growth and waste generation without considering their eco-environmental impacts and cointegrating long-term impact (Lee et al., 2016). Due to these limitations, academicians, policymakers, and government legislature are unable to evaluate the net effect of recycling on overall environmental pollution and economic growth.

To fulfill the gap, this study intends to estimate the economic and environmental impact of national MSW recycling in the US to achieve sustainable development. This potentially be a pioneering study to guide both academicians and policymakers to draft waste management strategies to attain sustainable development goals. Unlike previous studies, we employ a recent methodology of Bootstrapping Autoregressive Distributive Lag (ARDL) for exploring the short-term and long-term dynamic relationship to explain more variation from the time series data irrespective of constraints related to power and size of the data set. Therefore, it produces more efficient and comprehensive estimates as compared to former studies using simple correlation and causality procedures. Finally, this study estimates Granger-causality to examining the causal relationship among the variables under consideration (Granger, 1969).

The remainder of this study has been organized as the next section elaborates theoretical and empirical framework, followed by the material and methods, data analysis, and discussion. The last section summarizes recommendations and conclusion based on the findings of this study.

2. Theoretical framework

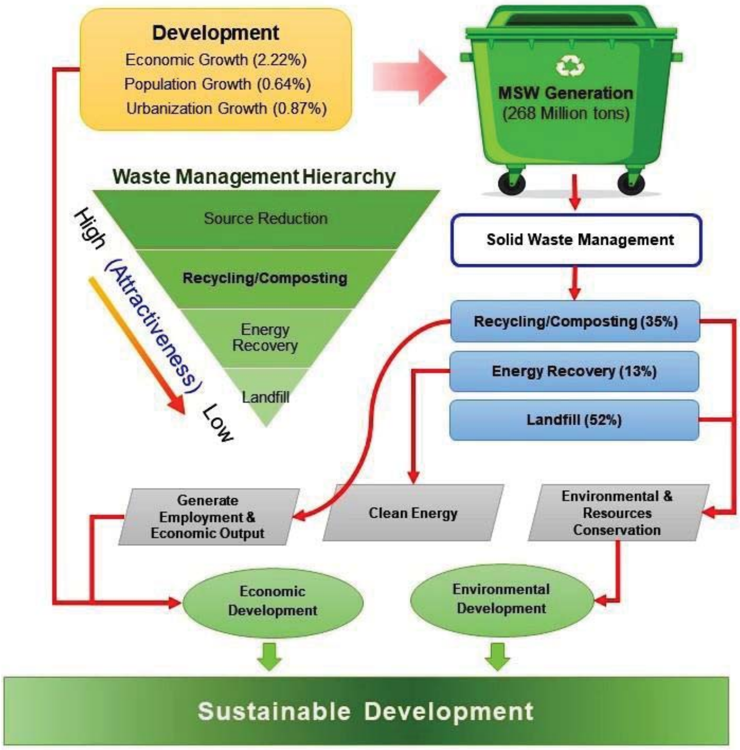
The ecological modernization theory postulates that environmental concerns that emerged from economic activities is neutralized by improving resource efficiency through technical innovation, such as circular economy (green) practices, that concurrently improve a country's (firm's) environmental and economic performance (Ferronato et al., 2019; Murphy and Gouldson, 2000; Scheinberg, 2003). Waste mitigation and resource conservation are emphasized in business operations, which are strongly linked with ecological sustainability and firm's economic performance (Arora et al., 2020; Jeng et al., 2020; Tseng et al., 2020). Extending the foundations of ecological modernization theory, this study examines the economic and environmental impact of MSW recycling in the US.

The flow of municipal waste starts from human activities that are attributed to economic growth, population growth, and urbanization (Lee-Geiller and Kütting, 2021; Minelgaitė and Liobikienė, 2019) as visualized in Figure 2. To efficiently manage municipal waste streams, waste management framework of the US is regulated by "Resource Conservation and Recovery Act" (RCRA, 1976). According to Environmental action program (EAP, 1990), "Waste management shall mean collection, transport, recovery, and disposal of waste, including the supervision of such operations and after-care of disposal sites". In doing so, the theory of waste management is originated on the expectation that waste management is to prevent waste causing harm to human health and the environmental quality to produce several positive economic fallouts (Pongrácz et al, 2004; Xing et al., 2020).

Waste management services are highly linked to environmental stewardship. In order to ensure sustainability benchmarks, environmental regulations are imperative to regulate MSW management techniques and the overall environment (Tseng et al., 2020; Tsai et a., 2020). Marques et al. (2018) exhibited that economic regulation in terms of tariff-setting is imperious for the waste industry due to higher vulnerability of market failures and lack of incentives. On the other hand, Di Foggia and Beccarello (2018) argued that Waste management and disposal services are prime sources that established the foundation of CE in EU. It is further highlighted that an efficient MSW management system improves people's welfare and lower waste-related taxes. Intervention in terms of price capping and yardstick regulation leads to potential savings two billion (bn) pounds out of 10.05bn pounds total tax revenue in 2015.

Figure 2 visualized the hierarchy and actual waste management practices, indicating that source reduction and recycling is considered the best solutions to manage waste, which saves resources for coming generations, save energy, supply raw material to industry, creating jobs, develop greener technologies, reducing the need for new landfills and combustors; all these factors lead to saving net carbon emissions and generate significant economic value (Cherubini et al., 2009; Robaina et al., 2020). The third method is combustion or incineration that refers to the burning of municipal waste under the control system to generate energy; however, this process caused several environmental hazards if eco-friendly incineration methods are not adopted. Lastly, waste landfill is the more conventional and less eco-friendly method in which waste is dumped into open land or process through a dedicated sanitary landfill to generate methane gas (Cherubini et al., 2009; EPA, 2020a). From the above stated municipal waste management tools, we are focused on MSW recycling and composting that accounts for 35% of the total MSW stream, leading to environmental conservation, minimizing health hazards, generating economic activities that leads to sustainable development. The complete process flow of this study is visualized in Figure 2.

Figure 2. Conceptual framework of Municipal Solid Waste Management USA



Source: Author's drawing

Note: US growth and waste management statistics represent the year 2017 and sourced from EPA (2020a) and Macrotrends (2020)

The traditional approach for examining economic activities is embedded with a single-dimensional idea of production, where natural resources (input) are converted into economic output (products) from one end to another end of the production process. In a market economy, the value of economic products gains significant attention, whereas the destruction of resources and the subsequent accretion of economic waste are usually overlooked (George et al., 2015). It is rational to expect that, if the global community does not engage in managing waste and recycling resources, the reserves of several resources soon disappear from the earth. George et al. (2015) designed a theoretical model for a CE based on two types of economic resources that include; recyclable input and polluting input. Their findings rejected the synopsis of the Environmental Kuznets Curve that higher economic growth maintains environmental quality. Instead, environmental sustainability can only be achieved through an increase in recycling ratio.

Prior studies are discussed waste management and recycling in two different dimensions. One strand of literature focused on the scientific procedure of MSW recycling and their eco-environmental efficiency across various industries and products (Badgett and Milbrandt, 2020), such as plastic waste (Robaina et al., 2020), C&D (Wang et al., 2019), metal recovery (Boesch et al., 2014), food waste (Philippidis et al., 2019), wastewater (Kobya et al., 2020) amongst others. The second strand of literature stresses reducing emissions and waste in the supply chain network through green supply chain practices in firm's operations (Hussain and Malik, 2020; Yu et al., 2020). The adverse effect of business operations on the environment is mitigated by implementing circular economy practices such as recycling and reuse and green design of products. The CE is based on the principle of resource conservation, where a circular design of products enables manufacturers to minimize resource dependence by recycling and remanufacturing processes (Rosa et al., 2020). Besides, circular design guides to minimize residuals from the production, which not only reduces resource dependence, energy consumption but also decreases financial cost (de Sousa et al., 2018; Morais and Silvestre, 2018). Table 1 provides a summary of the relevant literature.

Table 1. Summary of Literature Review

Authors	**Time/Country**	**Method**	**Findings**
Lee et al. (2016)	1990-2012 United States	Granger Causality	• No causality between Gross Domestic Product (GDP) and MSW generation • Causality confirmed between MSW greenhouse gas (GHG) generation • Total Waste increase GHG emissions • Recycling decrease GHG emissions
Magazzino et al. (2020)	1990–2017 Switzerland	Granger Causality and Machine learning	• Bidirectional causality between GDP and MSW generation • Recycling and Composting reduce GHG
Shaikh et al. (2020)	2020 Pakistan	Interview and Primary Survey	• Cost of e-recycling exceeds by 2.6-4.7 times than the estimated economic benefits for recycling workers
Mühle et al. (2010)	2010 Germany and UK	Descriptive analysis and used GHG emission calculators	• UK MSW management produce 175kgCO2 equivalents/t (eq) • Germany MSW generates 34kgCO2 equivalents/t. • Differences in both countries MSW emissions are attributed to *Recycling and Recovery*
Ayodele et al. (2018)	2017-2036 Six Zones of Nigeria	Population	• 89.99 toe (1046.43 GW h) of energy could be saved per annum by recycling the recyclable waste materials rather than producing new products from the virgin materials. • Electricity saving from recycling could provide electrical power for about 9.8 million people • 11.71 million USD economic benefits could be realized, which equivalent to about 16,562 jobs annually • 307.364 ktons CO2eq of GHG emission reduction through recycling

Babel and Vilaysouk (2016)	2011 Vientiane, Lao PDR	Atmospheric Brown Clouds Emission Inventory Manual (ABC EIM	• 110182 potential GHG tones year from MSW • Recycling, composting, and landfilling could reduce 91920 tones (47% reduction)
Maria et al. (2020)	2017 Luanda, Angola	Descriptive Analysis and used GHG emission calculator Land GEM model	• Landfilling cause 55.99% methane while 44.01% carbon dioxide • Mulenvos Landfill has contributed over 2 million Mg of CO2eq
Kristanto and Koven (2019)	2019 Depok, Indonesia	GHG emissions Calculated based on prevailing calculators and processes	• In the best-case scenario of MSW management, Composting generate 25,700 kg CO2-eq/day while controlled landfill generates 129,000 kg CO2-eq/day
Jiménez et al. (2018)	2018 Yucatan, Mexico	Field and inventory data for life Cycle Assessment (LCA)	• 22,343 tons of CO2-eq emissions would decrease annually by recycled aggregate concrete
Xin et al. (2020)	Beijing, China 2017	LCA	• An emissions reduction benefit of 70.82% could be achieved if kitchen waste and recyclables are sorted and recycled, and the residue is incinerated • Landfill would emit more GHG than incineration and composting.
Liu et al. (2020)	2001-2202 Florida	Fixed Effect regression	• 1% increase in recycling leads to 0.4% job growth in the overall solid waste and recycling industry
Park et al.,(2015)	1989-2011 Florida, USA	Descriptive analysis from Annual Survey of Public	• Strongest job growth (23.8%) in the SWMR industry from 2001-2011 • Material Recovery and Scrap Materials showed higher employment growth of 195% and 73% in the same period

		Employment and Payroll survey	
Davis (2013)	Queensland, Australia 2013	Descriptive Analysis from Waste Employment data	• MSW management generate green jobs in the private sector • Recycling generates 36 times more jobs than landfilling

Werikhe and Jin (2016) argued that green logistic operations help to fight climate change whilst improve the operational and financial performance of firms by embracing sustainable practices and an efficient waste management system (Hartmann et al., 2015; Khan et al., 2020). Luthra et al. (2016) emphasized that implementing recycling and reproducing principles in firm's logistics and supply chain activities contribute to waste reduction, promotes energy conservation, strengthens a sustainable environment with a reduction in carbon emissions (Herold and Lee, 2017; Hussain and Malik, 2020). MSW recycling is key elements to achieve sustainable development and provides opportunities to decrease oil consumption, carbon emissions and convert large quantities of waste into useful resources and energy that generate economic value, save resources and reduce landfilling (Nasrollahi et al. 2020; Tsai et a., 2020).

The adoption of recycling practices improves production efficiency, which leads to higher economic growth. Di Vita (2006) developed an endogenous growth model with exhaustible resources, which shows that recycling can enhance economic growth by increasing the total amount of input. In the circular economy, environmental and economic benefits are part and parcel, which are achieved simultaneously (Potting et al., 2017: Rosa et al., 2020). Utilizing Chinese and Pakistan firm's data, Khan and Qianli (2017) confirmed that recycling amongst other green supply chain practices are positively associated with firms profitability and environmental sustainability. Cankaya and Sezen (2019) estimated that green practices in business operations increase their efficiency, market share, sales, and profitability. Rehman Khan and Yu (2020) derived a positive association between green supply chain practices (recycling and green purchasing) and firm's financial and environmental performances in Pakistan. Similarly, Yu et al. (2020) estimated that sustainable practices, including Recycling and Remanufacturing in business operations improve firms image and their corporate social responsibility helps to boost organizational performance in Malaysia.

From the perspective of municipal waste, Cherubini et al. (2009) analyzed energy efficiency and environmental impact of the different waste management systems, namely; landfill with biogas combustion to produce electricity; landfill without biogas application; direct incineration of waste; sorting plant which splits the inorganic waste to produce electricity. Using LCA approach, they found that energy recycling significantly contributes to ecological savings. Also, material recycling potentially gains energy efficiency in treatment plants that fulfill Roma's 15% electricity needs and generate significant economic value with a lower ecological footprint. Turner et al. (2015) examined that resource efficiency and GHG emissions from waste recycling are the prime concern in the waste management sector. They performed LCA and quantified the benefits of multiple-source recycling towards mitigating emissions levels. Their findings showed that MSW recycling from all sources significantly reduces net emissions levels except paint and plasterboard. Turner et al. (2015) suggested the utilization of high-quality secondary data to measure the environmental impact of material recycling. Khandelwal et al. (2019) reviewed 153 studies from 2013 to 2019 to appraise multiple treatment options for municipal solid waste management (MSWM). They argued the heterogeneous nature of solid waste across different regions; therefore, no single treatment option is suggested for all the waste streams. However, an integrated MSWM system is found to be more suitable amongst others.

Minelgaitė and Liobikienė (2019) highlighted that waste generation relies on the economic status of EU countries. Their findings from the survey study revealed that the recycling behavior of local inhabitants significantly affects waste generation while reusing and reducing behaviors possess insignificantly effect. Similarly, Lee-Geiller and Kütting (2021) compare MSW practices in New York City and Seoul, indicating that environmental stewardship in terms of recycling is more prevalent where all stakeholders, i.e., individuals, private and public entities are responsible. Nabavi et al. (2017) performed an energy flow and LCA of solid waste from the municipality of Tehran, Iran. This study estimated that recycling and transportation consume 156 and 227 Gigajoules of energy to process 8500-ton waste by employing an artificial neural network. The estimated energy consumption leads to produce 18,884.03 Gigajoules energy output, therefore generate economic value whilst energy conservation improves environmental quality. Castillo et al. (2019) assessed convergence and performance in municipal waste treatment in EU countries and measured a cumulative performance indicator that includes; Recycling, incineration, landfill, and composting. Their estimated convergence rate showed that Northern and Central European countries are better performers, while Eastern European countries are worse performers in MSWM.

Mahmoudi et al. (2021) estimated the photovoltaic panels dismantle waste (25 to 28.5 Million Tons (MT) that include nonmetallic waste (25.69 MT), special metals (4.58 MT), and other metals (2.37 MT). These wastes generate a gross value of 36 to 42 Billion that provide economic spillovers to related supply chain actors. Recently, Steuer et al. (2021) disclose the role of ship recycling in Chinese circular economy practices, suggesting that recycling in the form of reuse and refurbishment of ships dispose of expired vessels that support the diminishing ship Recycling industry by simultaneously ensuring lowering environmental damages and securing natural resources. In the wake of COVID-19, recycling industry effect the most, particularly ship recycling that negatively affects south Asian economies in terms of employment that process 80% of the global dismantled ships (Rahman et al., 2021; Xing et al., 2020). By following LCA, Santillán et al. (2021) argued that domestic recycling of 13 information technology products minimizes supply risk as it decreases total imports and causes relocation of the import supply mix in EU.

Chun (2007) proposed a recycling system for big-middle cities to internalize recycling benefits and confirmed that recycling of household electrical waste potentially improves economic growth. Mohammadi et al. (2021) argued that the flow of electrical waste in five Caribbean islands is doubled than the global average, which is estimated to rise by 59,000 tons in 2025. This waste poses a significant threat to human health and waste resources due to the lower recycling ratio across these islands. To recover metals from combustion residuals, Boesch et al.

(2014) design the SWM ignition system with advanced technology that was found to improve metal recovery and doubled the savings of net carbon footprints from former procedures. Bueno et al. (2015) exhibited that recycling of materials reduces resource dependency and helps to control global warming because recycling of products saves large quantities of energy consumption required to produce new material and products. In order to deal with the higher volume of construction waste, Wang et al. (2019) proposed a waste management fee based on the nature of waste to be dumped or recycled.

For instance, Jin (2005) analyzed the relationship between economic growth and energy consumption based on the recycling principles of the economy. They found that recycling economy established co-existence between nature and provide a strategic option for the harmonious development of economic progress and energy consumption. Recently, Ferronato et al. (2019) compared the MSWM system between two states and highlighted that the recycling behavior of the Romanian public leads to missing EU goals for 2020, while Bolivia needs to formalize its waste management system, which needs further investment to increase recycling ratio in waste management.

Consider the diverse range of waste management and recycling studies, Li et al. (2018) conducted a systematic meta-analysis for Recycling and MSWM from 1992 to 2016. They identified that construction and demolition recycling is the potential gap in developed and developing countries. Similarly, Jin et al. (2019) confirmed construction and demolition recycling is a pragmatic solution to address socio-economic and environmental concerns globally. These studies reviewed recently published construction and demolition waste management research and highlighted pertinent research gap that includes; circular economy, big data analysis, and evaluate the environmental impact of construction and demolition of waste and recycling. In a recent scenario, Omolayo et al. (2021) reviewed several empirical studies on waste management and highlighted the research gap in terms of using transparent waste management data to implement MWM hierarchy through LCA. Their findings further revealed that a major strand of literature focused on the EU while a few studies draw a detailed analysis in US economy.

Although a plethora of researchers analyzed different waste management systems (Recycling, combustion, landfilling, etc), various recyclable (food, water, metals, ores, paper, plastic etc.), and draw its link with economic and environmental aspects by utilizing firm, industry, or survey level analysis. Yet, prevailing studies are limited to particular industries, scientific procedures, products, and municipalities. There is a dearth of empirical literature regarding the macro-level aggregate impact of national recycling on environmental quality and economic progress using national scale standardized indicators. This study intends to estimate the economic and environmental effects of MSW recycling in the US in the shorter and longer run.

3. Material and Methods

3.1. Theoretical Model

The prime objective of the paper is to analyze the effect of MSW recycling on economic growth and CO_2 emissions in the USA. In order to realize these objectives, we follow well-known theoretical frameworks include neo-classical growth and IPAT environmental model (Ehrlich and Holdren, 1971) to ascertain the economic growth and CO_2 emissions.

We follow the neoclassical growth model to derive economic growth (Paramati et al., 2017) through MSW recycling and energy efficiency:

$$GDP_t = f\,(CAP_t,\ LAB_t,\ RCY_t,\ EEF_t) \tag{1}$$

Where GDP, CAP, LAB, RCY, EEF represent economic growth, capital, labor, MSW recycling, and energy efficiency, while t represents time. The detail of these variables is given in the data section.

To derive the factors of Carbon emissions, prevailing literature extensively used the IPAT model (Paramati et al., 2017; Raskin, 1995; York et al., 2003). The IPAT framework is designed to integrate the most influential factors include; population, income, technology, and environmental impact as follows:

$$I=P\times A\times T \tag{2}$$

(I) denote environmental pollution, which is attributed to population (P), the scale of economic growth/activities or consumption per capita (A), and the technology level or efficiency defined by the amount of pollution per unit of economic activity or consumption (T). However, this model is extended to a stochastic form by Dietz and Rosa (1994, 1997), which is famously recognized as Stochastic Impacts by Regression on Population, Affluence, and Technology (STIRPAT) model. The STRIPAT model is just to test hypotheses empirically, which is nothing except an accounting equation. Hence; this study follows common characteristics of the STIRPAT model to derive an empirical modeling framework as:

$$CO_{2t} = f\,(POP_t,\ PI_t,\ RCY_t,\ EEF_t) \tag{3}$$

Where CO_2, POP, PI, RCY, EEF represent carbon emissions, population, per capita income, MSW recycling, and energy efficiency, while t represents time. The detail of these variables is given in the data section. Equation (3) explains the second model, which examines the influence of MSW recycling and energy efficiency by simultaneously considering other important factors in a multidimensional framework.

3.2. Data

This study utilizes quarterly[2] data of USA spans from Q1-1990 to Q4-2017, which include: CO2 emissions (CO_2) in metric tons per capita; MSW recycling (RCY) in tons; energy efficiency (EEF)[3]; economic growth measured as gross domestic product (constant 2010 US$) (GDP); gross fixed capital formation capital (constant 2010 US$) (CAP); total labor force aged above 15 (LAB); total population (POP), and finally per capita income (PI) is derived through the GDP divided by the mid-year population. These variables show different measurement units; therefore, it is imperative to generate a uniform measurement unit whilst overcome the issue of distributional properties. Following prior literature, we have converted all the variables in logarithm, which provides output in the form of elasticities that make the interpretation process easier (Paramati et al., 2017; Shahbaz et al., 2020). The data of all variables are sourced from World development Indicators (2018), except CO_2 and RCY, which are extracted from the official website of British Petroleum and the United States Environmental Protection Agency. The summary statistics are given below:

Table 2. Descriptive Statistics Results

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[2] To overcome the issue of shorter time span, we have utilized quadratic match-sum approach to transform yearly data into quarterly data by following Shahbaz et al. (2020); Razzaq et. al. (2020); Sharif et al (2019). The quadratic match-sum approach is quite inspective due to adjustment of cyclical variation in data and seasonality issues is avoided as this procedure decreases the point-to-point data variations (Shahbaz et al. 2017).

[3] Energy efficiency indicates the consumption of energy to produce one unit of GDP at purchasing power parity

Variables	Mean	Min	Max	Std. Dev.	Skewness	Kurtosis	Jarque-Bera	P-value
CO2	8.5898	8.4971	8.676 1	0.0558	0.0332	1.7020	2.0412	0.3604
RCY	10.8948	10.2764	11.1365	0.2353	-1.0977	3.3494	5.9711	0.0505
EEF	8.8222	9.0788	8.5677	0.1708	0.0574	1.6583	2.1910	0.3344
GDP	30.2047	29.8273	30.5134	0.2122	-0.4324	1.9358	2.2723	0.3210
CAP	28.5928	28.0684	28.9683	0.2686	-0.6797	2.2424	2.9262	0.2315
LAB	4.3087	4.2703	4.3399	0.0245	-0.2976	1.5862	2.8435	0.2413
POP	19.4873	19.3355	19.6045	0.0819	-0.2770	1.8795	1.8879	0.3891
PI	11.1316	10.9012	11.3323	0.1259	-0.4374	2.0632	1.9852	0.3706

Source: Author Estimations

3.3. Empirical Model

3.3.1 The bootstrap-ARDL

This study employs a recently developed bootstrap auto-regressive distributive lag (ARDL) bound testing approach to analyze the long-term cointegration relationship amongst the variables(McNown et al., 2018). This approach efficiently deals with the problem of low size and power characteristics that are not enabled in simple ARDL techniques by Pesaran and Shin (1999) and Pesaran et al. (2001). Moreover, bootstrap ARDL is an extension of the conventional ARDL bounds testing approach, which integrates a new cointegration test to improve the power of T and F tests. The previously known cointegration test follows two conditions while examining the cointegration relationship (Pesaran et al.,2001). First, it requires statistically significant coefficients of error-correction terms (ECTs). Secondly, the lagged independent variables also require significant coefficients. Pesaran et al. (2001) suggested that lower and upper bounds (critical bounds) are considered for the second situation, but there are no critical bounds for the first situation. In order to examine the first case, where ECTs are statistically significant, the test only be used if the model contains I (1) integrated of order one variables. Therefore, the conventional ARDL approach shows weak explanatory and power characteristics (Goh et al., 2017; McNown et al., 2018).

These issues are addressed by utilizing the bootstrap ARDL bounds testing approach, which employs an additional F-test on the lagged coefficients of independent variables (Goh et al., 2017). The bootstrap ARDL approach overwhelms the response by allowing the variables with mixed order of integration, which is more appropriate for dynamic models with more than one independent variable that addresses the problem of inconclusive evidence from traditional ARDL bounds testing approach (McNown et al., 2018). Following Goh et al. (2017), equation 1 shows the mathematical specification of the traditional bootstrap-ARDL bounds testing procedure with three explanatory variables.

$$y_t = \sum_{i=1}^{p} a_i y_{t-i} + \sum_{j=0}^{q} \beta_j x_{t-j} + \sum_{k=0}^{r} \gamma_k z_{t-k} + \sum_{i=1}^{s} \tau_i D_{t,1} + u_t \qquad (4)$$

Where i, j, k, and l represent the lags $(i = 1,2 \dots . p; j = 0,1,2, \dots , q; k = 0,1,2, \dots . r; l = 0,1,2, \dots . s)$, t denotes time, y_t is the dependent variable, x_t and $z_t$are the independent variables, $D_{t,1}$ is a break year dummy based on Kim and Perron's (2009) unit-root test, β and γ denotes the coefficients of lagged independent variables, τ is the parameter of the dummy variable, and u_t

represent the error terms with zero means and constant variance. The error-correction procedure of the model is as follows:

$$\Delta y_t = \varphi y_{t-1} + \gamma x_{t-1} + \Psi z_{t-1} + \sum_{i=1}^{p-1} \lambda_i y_{t-i} + \sum_{j=1}^{q-1} \delta_j x_{t-j} + \sum_{i=1}^{r-1} \pi_k z_{t-k} + \sum_{i=1}^{s} \omega_i D_{t,1} + u_t \quad (5)$$

The parameters from the above equation show the following function; $\varphi = \sum_{i=1}^{p} a_{i,}\ \gamma \sum_{i=0}^{q} \beta_{i,}$ and $\Psi = \sum_{i=0}^{r} \gamma_{i.}$. Similarly, $\lambda_i, \delta_j, \pi_k$, and ω_i comprise the related functions from the first equation. Equation 2 is derived from Equation 1 by transforming a vector auto-regression in the levels into its error-correction form, while Equation (3) is calculated by utilizing constant-term ($\tilde{c}$) in following unconditional model:

$$\Delta y_t = \tilde{c} + \tilde{\varphi}\, y_{t-1} + \gamma x_{t-1} + \tilde{\Psi} z_{t-1} + \sum_{i=1}^{p-1} \tilde{\lambda}_\iota y_{t-i} + \sum_{j=1}^{q-1} \tilde{\delta}_\iota x_{t-j} + \sum_{i=1}^{r-1} \tilde{\pi}_\iota z_{t-k} + \sum_{i=1}^{s} \widetilde{\omega_\iota} D_{t,1} + \tilde{u_t} \quad (6)$$

To confirm the cointegration among the variables x_t, y_t, and z_t, equation (3) requires the rejection of following three null hypotheses:

- F-1 test comprises over relevant ECTs ($H_0: \varphi = \gamma = \Psi = 0$) against ($H_1 \neq \varphi \neq \gamma \neq \Psi \neq 0$)
- F-2 test comprises over independent variables ($H_0: \varphi = \gamma = 0$) against ($H_1: \gamma \neq \Psi$)
- F-3 test comprises over lagged dependent variable ($H_0: \varphi = 0$) against ($H_1: \varphi \neq 0$)

This is pertinent to mention that the conventional ARDL approach only produces critical values of bounds test for F1 and T-tests; however, it fails to provide test statistics for F-2 based on the lagged independent variable. The bootstrap-ARDL framework enables this feature, which simultaneously provides critical values for all three tests whilst produce robust estimates (McNown et al., 2018).

4. Results and Discussions

4.1 Unit root Tests

Before estimating the time series model, it is imperative to affirm the stationarity properties of the variables. Therefore, this study employs both conventional augmented Dickey-Fuller (ADF) as well as structural break Kim and Perron (2009) unit root tests. From Table 3, both of the tests confirm that all variables are integrated of order one at a 1 % level of significance. Also, the Kim and Perron unit root test highlights significant structural breaks in the given time series. Recognizing the same, the bootstrap ARDL model is the most appropriate technique which efficiently deals with structural breaks and dynamic stochastic trend.

Table 3. Results of unit root analysis

Variables	**Traditional ADF Test**		**Structural Break ADF Test**		
	T-Statistics	**P. Value**	**T-Statistics**	**P. Value**	**Break Year**
$CO2_t$	-1.574	0.482	-4.108	0.451	2014 Q4
RCY_t	1.573	0.968	-4.022	0.505	2010 Q1
EEF_t	-0.305	0.912	-3.891	0.593	2009 Q1
GDP_t	-2.212	0.205	-3.212	0.921	2017 Q4

CAP_t	-2.129	0.235	-4.073	0.475	2004 Q3
LAB_t	-0.849	0.788	-2.828	0.981	1999 Q1
POP_t	-2.352	0.164	-2.301	0.999	1984 Q1
PI_t	-1.477	0.529	-4.334	0.318	2008 Q1
$\Delta CO2_t$	-6.527***	0.000	-6.920***	0.000	2012 Q3
ΔRCY_t	-5.905***	0.000	-7.725***	0.000	2003 Q2
ΔEEF_t	-6.180***	0.000	-8.660***	0.000	2016 Q4
ΔGDP_t	-6.762***	0.000	-9.110***	0.000	2010 Q4
ΔCAP_t	-12.057***	0.000	-12.950***	0.000	2007 Q1
ΔLAB_t	-10.324***	0.000	-8.226***	0.000	2010 Q1
ΔPOP_t	-8.655***	0.000	-9.988***	0.000	1995 Q4
ΔPI_t	-6.160***	0.000	-13.356***	0.000	2009 Q2

Source: Author Estimations. Note: *** represents the significance level at 1%.

4.2 The Bootstrap ARDL bound testing framework

After confirmation of variables stationarity, this study moves to the analysis of the cointegration relationship between driving factors of economic growth and between carbon emissions and its determinants, which focused on MSW recycling and energy efficiency beside others. In doing so, this study employs bootstrap ARDL to confirm the existence of long-term cointegration equilibrium between the variables of both models. The bootstrap ARDL bound testing framework is superior to the traditional ARDL model (Shahbaz et al., 2020), which concurrently provides the values of joint F-test on the lag of all variables, t-test on the lag of dependent variable, and the new t-test on the lag of regressors that helps to efficiently test the cointegration equilibrium among the related variables. While estimating the cointegration relationship through the bootstrap ARDL model, the selection of optimum lag length is compulsory because incorrect lag order distorts empirical evidence. Hence, the optimum lag length is decided based on Akaike Information Criteria (AIC) that is widely accepted due to its higher power (Lütkepohl, 2006). The second column of Table 4 reports the lag length of all the variables in chronological order from both models.

In the bootstrap ARDL cointegration framework, F-value and t-value have bootstrapped for examining long-term cointegration associations among the variables. Table 4 contains the empirical findings of bootstrap ARDL model, which confirms the rejection of null hypothesis on the basis of F-test and t-test on lagged level of the dependent variable, where Model-1 variables (GDP, capital, labor, MSW recycling, energy efficiency), and Model-2 variables (populations, and per capita income, MSW recycling, energy efficiency) are considered as independent. The t-test based on lagged explanatory variables is also rejected the null hypothesis of no cointegration. This indicates that the joint F-test and t-tests from both models confirm the existence of a long-term equilibrium cointegration relationship among variables at the 1% level of significance.

The diagnostic test ‘Q-stat’ accepts the null hypothesis from both models, which indicates that all the relevant variables have standard variance and populace that confirm the normality of the data distribution. These results are also endorsed by Jarque-Bera statistics (refer to Table-2). Moreover, the findings also affirm that there is no serial-correlation among the variables of both models (Pesaran et al. 2001).

Table 4. Results of Bootstrapped ARDL Cointegration Analysis

Bootstrapped ARDL Cointegration Analysis						**Diagnostic tests**			
Estimated Models	**Lag length**	**Break Year**	**F_{PSS}**	**T_{DV}**	**T_{IV}**	**R^2**	**Q-stat**	**LM (2)**	**JB**
Model-1	2, 2, 2, 1, 1	2009 Q1	18.578***	-4.059***	-3.874***	0.954	5.215	1.246	0.421
Model-2	2, 1, 1, 1, 1	2014 Q4	13.775***	-3.971***	-3.249***	0.901	6.024	2.027	0.269

Model-1: $GDP_t = f(CAP_t, LAB_t, RCY_t, EEF_t)$

Model-2: $CO2_t = f(POP_t, PI_t, RCY_t, EEF_t)$

Note: The asterisks *** and ** show significance at 1% and 5% levels. The Akaike Information Criterion (AIC) decides the optimal lag length. FPSS is the F-statistic based on the asymptotic critical bounds that is generated from the use of bootstrap method. TDV is the t-statistic for the dependent variable and TIV is the t-statistic for the independent variables, LM is the Langrage Multiplier test and followed by JB for the Jarque-Bera test.

Source: Author Estimations

4.3 Long-term estimates

The confirmation of the cointegration relationship among the variables enables us to examine long-term and short-term elasticities. Table 6 contains the long-term estimates from both models. Model-1, where the economic growth is the dependent variable, shows that a 1% increase in capital, labor, MSW recycling, and energy efficiency significantly improves the economic growth by 0.371%, 0.224%, 0.317%, and 0.489%. Similarly, Model-2, where carbon emissions are dependent variable, shows that a 1% growth in MSW recycling and energy efficiency significantly reduces the level of carbon emissions by 0.209 % and 0.285%. The results further imply that a 1% increase in population and per capita income significantly increase carbon emissions by 0.401% and 0.197% at a 1% level of significance. There is theoretical plausibility as the signs of all coefficients of independent variables are according to theory and a major strand of empirical literature endorsed our findings.

In order to develop a sequester measure of MSW recycling, this study uses the time series data of national MSW recycling and composting, which include paper and paper board, rubber and leather, wood, plastics, electronics, glass, metals, yard trimming, food waste and exclude hazardous waste substances. Bearing the scope of study in mind, this paper assumes recyclables are recycled at once a year. The life cycle of recyclables in subsequent processing and their output efficiency is considered constant to isolate a national impact of MSW Recycling over the years. Although the marginal effects of emissions mitigation and economic growth contribution is lower in magnitude; however, countries around the globe focusing on recycling as a policy measure to combat emissions. The MSW recycling found to mitigate emissions in Switzerland (Magazzino et al., 2020), US (Lee et al., 2016), Lao PDR (Babel and Vilaysouk, 2016).

Besides direct impact, MSW Recycling indirectly saves a significant portion of land and related GHG emissions (methane and carbon) from landfills. The summation of direct, indirect, and multiplier effects in terms of natural resource conservation and energy efficiency is a complicated matter; however, it implies that the marginal impact of MSW Recycling has significant relevance for environmental sustainability. According to the World Bank (2018), EU and Japan are continuously reducing their landfilling ratio by employing different regulatory and economic instruments such as green tariffs and diverting waste stream towards recycling. However, recycling has a higher processing cost than landfilling and incineration. There is also an infrastructure gap that creates a bottleneck in MSW management process. Therefore, government regulation and MSW-related infrastructure financing are imperative to minimize environmental hazards from waste disposal.

On the other hand, the economic benefits of MSW recycling in terms of job creation is estimated by Liu et al. (2020), who revealed that a 1 % increase in recycling leads to 0.4% job growth MSW Recycling industry in Florida. Similarly, 23.8% jobs growth is estimated in MSW management industry in Florida from 2001-2011. Davis (2013) estimated that recycling generates 36 times more green jobs than landfilling in Queensland, Australia. Summing up environmental and ecological benefits, Ayodele et al. (2018) projected a net saving of 1046 GWH of energy by recycling of MSW Recyclables rather than using fresh material for new products from data of six Zones in Nigeria. This saving can fulfill the need of 9.8 million people and saves 307.364 ktons CO2eq of GHG emission reduction accompanied with economic value of worth 11.71 million USD which is equivalent to 16,562 jobs. George, Lin, and Chen (2015) argued that recyclable waste as an input of production and suggests that the marginal product of the recyclable input and the recycling ratio are two critical determinants of economic growth.

There is no doubt that MSW procedures itself caused emissions and required energy to collect, process, or disposal of waste. Table 5 reports the estimates of the GHG emissions from different waste management processes, indicating that landfilling is the higher contributor, followed by wastewater treatment and composting. The relative share of composting is significantly lower, suggesting a higher net savings of emissions. Recycling is considered as an alternative tool to reduce landfilling and related emissions in EU and Japan (World Bank, 2018), Indonesia (Kristanto and Koven, 2019), Angola (Maria et al., 2020), China (Xin et al., 2020). Although recycling cost is higher, however, it generates a greater margin of net emissions saving amongst other procedures.

Table 5. US Greenhouse Gas Emissions from Waste Management

Waste Sector	Landfills	Wastewater treatment	Composting	Total
1990	179.55	18.73	0.72	199.00
1995	174.19	19.74	1.65	195.58
2000	141.41	20.19	2.83	164.43
2005	131.32	19.83	3.53	154.68
2010	124.06	19.51	3.47	147.04
2015	111.31	19.33	4.02	134.65
2018	110.56	19.22	4.66	134.44

Source: Environmental protection agency EPA (2020b).(Emissions in MMT of carbon dioxide equivalents)

Our empirical findings are similar to Cherubini et al. (2009), who found that recycling significantly contributes to ecological savings, and recycling potentially gains energy efficiency in treatment plants in Roma (Italy). Similarly, insights are observed by Khandelwal et al. (2019) and Turner et al. (2015), who concluded that recycling not only creates wealth from waste but also minimizes environmental hazards in terms of reduction of net Carbon/GHG emissions level (Boesch et al., 2014). In the same vein, Bueno et al. (2015) exhibited that recycling of materials diminishes resource dependency and helps to control global warming because recycling products saved large quantities of energy consumption required to produce new material and products. Nabavi et al. (2017) also echoed our findings and suggested that recycling leads toward energy efficiency, which also generates economic value whilst energy conservation improve environmental quality.

Although a large extent of literature highlighted the environmental and economic benefits of recycling, however, our results are different from them because it provides a national insight from country-level analysis as converse to industry, products, or particular municipality recycling. Also, these studies are lacking the measuring feature of environmental and economic impact in terms of net terrestrial emissions and the overall economic growth of a country. The estimated elasticities pave the way towards measuring the marginal contribution of MSW recycling towards economic growth and ecological sustainability in both the short-run and long run. These findings also adhere to the suggestion of Turner et al. (2015), who advised conducting future research by utilizing high-quality secondary data. There is no doubt, without recyclable waste management and energy efficiency, it is impeded to achieve a sustainable environment in the long-term.

The dummy variables (the Year 2014) from both models show a significant and positive influence on economic growth and carbon emissions. The year 2014-Q2 attributes to oil-glut in the global market, and the US had the key player that led to lower oil prices due to excess supply driven by receding geopolitical factors, OPEC policies, and booming US's oil production. Therefore, the selected dummy has captured a profound impact on both the dependent variable, economic growth, and carbon emissions. Moreover, the validity of these parameters is contingent on the stability analysis, which confirms that error terms are normally distributed from both models. Similarly, test statistics show that both of the models have no serial-correlation, and no heteroscedasticity, which is also authorized by Ramsey reset test statistics. The explanatory variables of Model-1 explained 87.9 % of total variations in economic growth, while explanatory variables of Model-2 explained 83.6 % of the explained variations in carbon emissions that validates the property of goodness of the fit measure. The models are also free from autocorrelation that is endorsed by Durbin-Watson test statistics. Finally, CUSUM and CUSUM_{SQ} tests confirm the stability (reliable) of all estimates, which is observed from Figure-3 and Figure-4.

Table 6. Results Bootstrapped ARDL Cointegration Analysis (Long Run)

Dependent Variable = GDP_t				**Dependent Variable = $CO2_t$**		
Variable	**Coefficient**	**T-Stat**	**P. Value**	**Coefficient**	**T-Stat**	**P. Value**
Constant	0.297***	3.022	0.000	1.089***	4.159	0.000
CAP_t	0.371***	2.984	0.001	-	-	-
LAB_t	0.224***	3.448	0.000	-	-	-
RCY_t	0.317***	4.051	0.000	-0.209***	-4.366	0.000
EEF_t	0.489***	5.489	0.000	-0.285***	-4.015	0.000
POP_t	-	-	-	0.401***	3.146	0.000
PI_t	-	-	-	0.197***	5.189	0.000

D_{2014}	0.198**	2.018	0.049	0.084***	6.317	0.000
R^2	0.879			0.836		
Adj - R^2	0.871			0.824		
Durbin Watson	2.157			1.973		

Stability analysis

Test	**F-Statistics**	**P. Value**	**F-Statistics**	**P. Value**
χ^2_{NORMAL}	1.017	0.353	1.066	0.270
χ^2_{SERIAL}	1.368	0.494	0.972	0.551
χ^2_{ARCH}	1.128	0.361	1.311	0.386
χ^2_{HETERO}	1.045	0.411	0.844	0.411
χ^2_{RESET}	1.034	0.280	1.346	0.173
CUSUM	Stable		Stable	
CUSUMsq	Stable		Stable	

Source: Author Estimations . Note: ***, ** and * represent level of significance at 1%, 5% and 10% .

4.4 Short-term Estimates

Table 7 reports short-term estimates from both models. Model-1, where the economic growth is the dependent variable, shows that a 1% growth in capital, labor, MSW recycling, and energy efficiency stimulates economic growth in the short-term by 0.108%, 0.297%, 0.157%, and 0.281%. Similarly, Model-2, where carbon emissions are dependent variable, indicates that a 1% increase in MSW recycling and energy efficiency significantly mitigates carbon emissions in the short-run by 0.089%, and 0.197% at a 1% level of significance. Also, a 1% increase in per capita income significantly increases carbon emissions by 0.215% at a 1% level, while the population exerts an insignificant but positive influence on emissions level in the short-term. The sign and significance of short-term elasticities (parameters) are similar to long-term elasticities, however lower in magnitude. It indicates that MSW recycling and energy efficiency are significant contributors to economic growth and environmental quality in both the short-run and long-run. However, the marginal impacts are more pronounced in the long-run. The dummy variable confirms that the selected year significantly contributes to economic growth and environmental pollution.

The error correction terms (ECMs) from both models are also negative and significant at the 1% level, which confirms the speed of convergence towards long-term equilibrium in case of any shock or dis-equilibrium in the short-term. The coefficient values disclose that any deviation from the long-term path is adjusted by 22.9% in the case of Model 1, and 8.9% in the case of Model 2. The negative ECM values reiterate the presence of a long-term relationship among variables (Banerjee et al., 1998). Unlike previous studies, where a simple causal link draws without integrating previous year's effect, which distorts true parameters of current year’s. There is no doubt that the current year's recycling rate and economic growth depend upon the previous year’s performance in time series models. Therefore, time lag effects are necessary to derive reliable estimates; otherwise, model parameters overestimate the elasticities. Similar to the long-term models, all diagnostic test validates the precision and efficiency of estimates. These tests confirm that both short-term models are well-designed, possess no auto-correlation, and white heteroscedastic. Further, the stability and reliability of both empirical estimates are also endorsed by CUSUM and CUSUMsq tests.

Table 7: Results Bootstrapped ARDL Cointegration Analysis (Short Run)

Dependent Variable = GDP_t				Dependent Variable = $CO2_t$		
Variable	**Coefficient**	**T-Stat.**	**P. Value**	**Coefficient**	**T-Stat.**	**P. Value**
Constant	0.015***	5.252	0.000	1.058***	4.145	0.000
ΔCAP_t	0.108***	3.251	0.000	-	-	-
ΔLAB_t	0.297***	2.769	0.001	-	-	-
ΔRCY_t	0.157***	3.357	0.000	-0.087***	-5.018	0.000
ΔEEF_t	0.281***	8.667	0.000	-0.197***	-3.397	0.000
ΔPOP_t	-	-	-	0.018	0.431	0.668
ΔPI_t	-	-	-	0.215***	4.489	0.000
D_{2014}	0.038***	3.887	0.000	0.028***	5.108	0.000
ECM_{t-1}	-0.229***	-4.018	0.000	-0.089***	-3.201	0.000
R^2	0.783			0.605		
Adj - R^2	0.779			0.591		
Durbin Watson	2.017			2.199		

Stability analysis

Test	**F-Statistics**	**P. Value**	**F-Statistics**	**P. Value**
χ^2_{NORMAL}	1.025	0.498	1.196	0.556
χ^2_{SERIAL}	1.359	0.297	0.894	0.638
χ^2_{ARCH}	1.587	0.137	1.053	0.294
χ^2_{HETERO}	1.271	0.556	1.443	0.301
χ^2_{RESET}	1.028	0.271	0.921	0.182
CUSUM	Stable		Stable	
CUSUMsq	Stable		Stable	

Source: Author Estimations. Note: ***, ** and * represent level of significance at 1%, 5% and 10%

Figure 3. CUSUM and CUSUM of Square for the model of Economic Growth

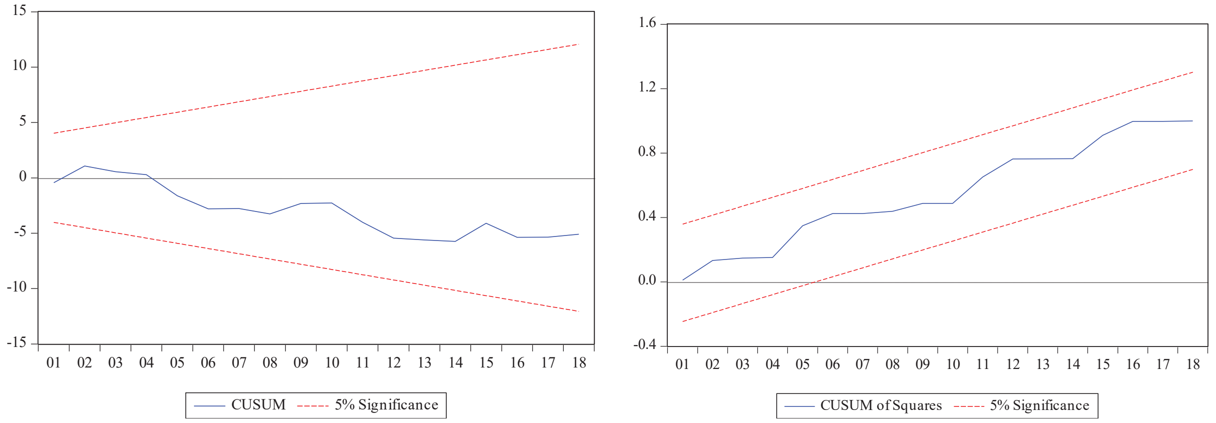
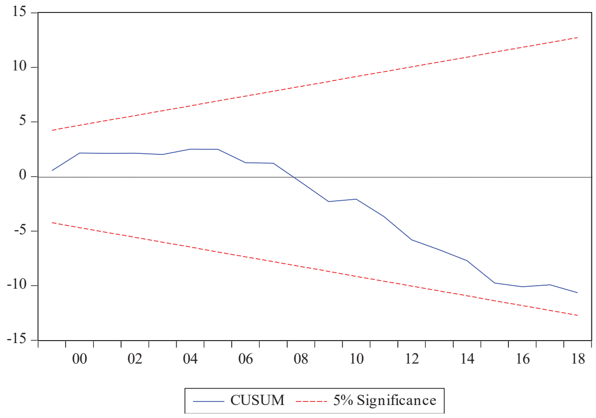
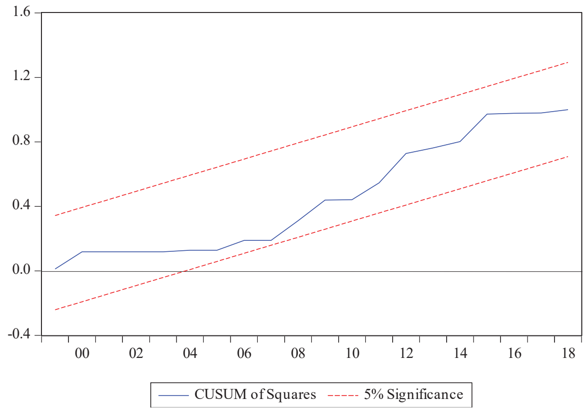


Figure 4. CUSUM and CUSUM of Square for the model of CO_2 Emissions





4.5 Granger Causality

Table 8 reports the findings of the Granger-causality test. From the given probability values, this study observes the reliability of estimates, suggesting the null hypothesis related to Granger no-causality. The results confirm the bi-directional causality between energy efficiency and CO2 emissions, between energy efficiency and economic growth, between economic growth and CO2 emissions, while a uni-directional causality from MSW recycling to economic growth, CO2 emissions, and energy efficiency. It implies that MSW recycling not only causes economic growth but also affects energy efficiency and emission levels significantly. Thus, any policy intervention regarding recycling significantly affects CO2 emissions, energy efficiency, and economic growth. However, no reverse causality exists from CO2 emissions and economic growth to recycling, suggesting that higher economic growth and emissions do not persuade the recycling rate. Therefore, policy intervention is necessary to increase the recycling rate as higher income does not lead to a higher recycling ratio.

The reverse causality between economic growth and CO2 highlight that both variables caused each other; therefore, in order to break the casual movement from economic growth to CO2, recycling can play an imperative role as it caused lower CO2 by simultaneously contributing to economic growth. These results conclude that recycling is an instrument that positively caused economic growth and energy efficiency while negatively caused carbon emissions; higher energy efficiency subsequently caused higher economic growth and lower emissions. Concludingly, recycling contributes to economic growth and mitigates emissions directly as well as through the channel of energy efficiency.

Table 8: Results of Granger causality

Null Hypothesis:	**F-Statistic**	**Prob.**
RCY does not Granger Cause GDP	4.184*	0.052
GDP does not Granger Cause RCY	2.286	0.143
RCY does not Granger Cause CO2	12.189***	0.000
CO2 does not Granger Cause RCY	0.444	0.511
EEF does not Granger Cause CO2	18.115***	0.000
CO2 does not Granger Cause EEF	22.871***	0.000
EEF does not Granger Cause GDP	9.246***	0.001
GDP does not Granger Cause EEF	8.492***	0.007
EEF does not Granger Cause RCY	2.630	0.117

RCY does not Granger Cause EEF	5.496**	0.027
GDP does not Granger Cause CO2	24.166***	0.000
CO2 does not Granger Cause GDP	15.146***	0.000

Source: Author Estimations.Note: ***, ** and * represent level of significance at 1%, 5% and 10% .

5. Policy Recommendations

This study suggests pertinent policy inference as follows: First, Recycling of waste is used as an instrument of carbon abatement policies. The recycling of materials reduces the burden on natural resources and helps to control emissions levels because MSW recycling saved large quantities of resources and energy consumption required to produce new material and products. Second, the government should target recycling policy as a stimulator of economic growth amongst others because it creates the economic value from waste whilst provide employment opportunities to both skilled and unskilled labor force that collect and process waste from communities. Third, government and policymakers should also consider the previous transmission channel and causality to devise the recycling policies, which simultaneously affect energy efficiency, environmental quality, and economic growth. Fourth, in order to improve the recycling ratio amongst other waste management tools, governmental should incentivize the stakeholders that belong to the recycling industry by simultaneously implementing municipal fees or penalties for non-recyclable materials. Lastly, a set of stringent laws should implement that can force industries to reproduce their goods from the recycling process. A certain ratio of material recycling in the production process has a profound impact on overall recycling growth. Therefore, the government should set a minimum threshold for all industries according to the use of recyclable material in their production process instead of relying on subjective commitments. Besides strict laws, tax exemptions for the use of recyclable materials in the production process, financing of recyclable-related infrastructure can encourage recycling and eco-friendly production.

6. Conclusion

This study estimates the effect of MSW recycling on economic growth and environmental quality of the United States. Utilizing quarterly data from 1990 to 2017, this study employs bootstrap ARDL modeling for investigating the cointegration relationship among variables. This study comprises two models that focused on MWS recycling. The first model contains the driving factors of economic growth, while the second model comprises the determinants of carbon emissions. This study employs both simple and structural unit roots tests, which confirm that all variables are integrated, while bootstrap ARDL bound testing validates the long-term cointegrating relationship among variables of both models. This study reveals that MSW recycling and energy efficiency not only stimulate economic growth but also significantly reduced the level of carbon emissions in both the short-term and long-term. The elasticities coefficient values from both models show a higher magnitude in the long-run and a lower magnitude in the short-run, suggesting that the carbon emissions-reducing effect of recycling and energy efficiency is higher in the long-term as compared to the short-term. The Granger causality test confirms bi-directional causality between energy efficiency and carbon emissions, between energy efficiency and economic growth, between economic growth and carbon emissions, while a uni-directional causality from MSW recycling to economic growth, carbon emissions, and energy efficiency.

These results imply that any policy intervention concerning MSW *Recycling* significantly causes environmental pollution and economic growth.

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