A Review of Waste Management Technologies Towards a Circular Economy in the Philippines

Lynlei L. Pintor[1], Josel B. Godezano[2], and Mattheus Imcon V. Abris[2]

ABSTRACT

Circular economy (CE) refers to the production and consumption of goods through closed loop material flows that internalize environmental externalities linked to virgin resource extraction and the generation of waste. CE has not materialized in the Philippines since the implementation of the Ecological Solid Waste Management Act in 2000. Several research studies have already been conducted focusing on the various aspects related to solid waste management. However, there is paucity of the available information related to waste management technologies that can stir the circular economy in the country. This study assessed the science, technology, and innovation on waste management in the Philippines within a ten-year period from 2009 to 2019. Content analysis was done on the research conducted and technologies generated to assess the role of science, technology, and innovation on waste management. Results revealed that several studies mainly focused on waste characterization, reuse, recycle, reduce or 3Rs, policy development and implementation, brand audits, and public and health effects of plastic wastes. Most of the studies conducted were quantitative in nature. On generated technologies, most of the reports focused on refuse-derived-fuel, vermin-composting, gravity-driven Materials Recovery Facility (MRF), bulb eater machine, and plastic bricks. Despite the annual increase in waste generation, waste management still receives poor attention from the government. Thus, achieving a circular economy will take time in the country.

Keywords: *waste management, circular economy, research, development*

INTRODUCTION

The volume and complexity of wastes associated with the Philippines' modern and emerging economy is a prevalent problem especially in the urban areas of the country (EMB 2019; SEPO 2017; Castillo & Otoma 2013; Atienza 2011a). The country's waste generation continues to rise due to the rapid increase of population, improvement of living standards, fast economic growth, and industrialization. It reportedly grew from 37,427 to 40,087 tons/day in 2012 and 2016, respectively. Further increase was projected to about 49,000 tons/day this year. Therefore, waste management remains a major challenge to us unless addressed. Waste will continuously affect the environment and the generations to come.

---

[1]Corresponding Author: Lynlei L. Pintor, Ecosystems Research and Development Bureau. College, Laguna, Philippines. Email:lynlei14@gmail.com

[2]Toxic and Hazardous Waste Research Development and Extension Center, Quezon City, Philippines. Email:godezano1983@gmail.com

[2] Ecosystems Research and Development Bureau. College, Laguna, Philippines. Email:mivabris.work@gmail.com

Globally, circular economy (CE) principles on waste handling replaced existing unsustainable and linear waste management schemes to address the concerns on waste and to support the global adoption of the concept of sustainable development (Luttenberger, 2020). The traditional linear system of "take-make-consume-dispose" is being addressed through CE to improve sustainability of resources and safeguard the environment for the future generations (Marquez & Rutkowski 2020). CE according to Sauvé et al. (2016) refers to the production and consumption of goods through closed loop material flows that internalize environmental externalities linked to virgin resource extraction and the generation of waste. CE was defined by Geissdoerfer et al. (2017) as the regenerative system in which resource input and waste, emission, and energy leakage are minimized by slowing, closing, and narrowing material and energy loops, which can be achieved through long-lasting design, maintenance, repair, reuse, remanufacturing, refurbishing, and recycling. The concept of CE is a powerful bridging concept to foster the fundamental links among resource use, waste, and emissions which in turn contributes to the integration of environmental and economic policies.

The Philippines has already taken steps to address the global challenge of resource sustainability and waste management through the policy implementation of the Republic Act (RA) 9003 or its National Solid Waste Management Strategy. The government acknowledges that there are matters to be clarified and policy gaps to be identified in the implementation of RA 9003. It strives to provide local government units (LGUs) with better access to technologies, innovations, and research on waste management. However, the transition from a linear-based to CE-based waste management system remains very challenging in the country. Open dumping system remains the general practice of waste disposal. With this, scarcity of new landfill sites is the main problem because there is a growing number of garbage generated by the Filipinos. Many landfills in the Philippines are already filled up to their capacity and forced to close. One of the examples was the premature closure of San Mateo Waste Disposal Facility (SMWDF) in 2000, a dumpsite for the garbage disposal of most of the solid waste generated in Metro Manila (Castillo & Otoma 2013). Controlled dumpsites and sanitary landfills are still very limited (NSWMC 2016). Because of the current linear scheme, the volume of wastes continues to rise with the increasing population (Luttenberger 2020), which necessitates the substantial restructuring of the system to achieve compliance with the CE.

Although Circular Economy has been implemented to the fullest in terms of theory, practice, and policy in some of the developed countries in the world, it is still poorly researched in developing countries (Marquez & Rutkowski 2020). In the Philippines, available technologies and innovations on waste management that can help achieve a CE are poorly assessed. No available study has been found on how to maximize the STI waste management system in the country. This study examined the opportunities for implementing the CE principle in the Philippines' ecological waste management scheme based on the existing science, technologies, and innovation on waste management.

Solid Waste Management Practices

During the last ten years, many pressing issues and environmental problems concerning e-waste have caught the attention of several researchers in the Philippines. Studies on solid waste management (SWM) have evolved in four thematic areas which include solid waste management and practices, policy development and implementation, waste integration, conversion and recovery, and electronic wastes recycling and management. The study of Antonio (2010) and Chiu (2010) mainly focused on the collection trends on recyclables and best practices on waste recycling (Table 1). Metal and plastic scraps had high exports while wastepaper and glass waste had high imports (Antonio 2010). Waste recycling led by LGUs, or voluntary collection, was included among the best recyclable collection practices. The participation of the informal sector to the initiatives by the LGUs successfully accounted for a waste disposal rate of 25% which is higher than the target rate. ‘Linis Ganda’ is one of those initiatives. It coordinates junk shop cooperatives to formalize the roles of eco-assistants. Recycling technologies and facilities transform wastes to useful raw materials or finished products. Studies on synergy in urban solid waste management systems, waste management through recycling, and waste assessments and brand audits were conducted by Tinio et al. (2019), Palomar et al. (2019), and Rola (2019). Constructed system dynamics model demonstrated the synergy in the urban solid waste management system by exhibiting the effect of waste diversion and public participation on the volume of disposed waste (Tinio et al. 2019). The synergy in the urban solid waste management system in Malolos City, Bulacan demonstrated the constructed system dynamics model through showing the effect of waste diversion and public participation on the volume of disposed waste. Organic wastes comprise more than 50% of generated wastes. Policy actions like the implementation of plastic bag regulations lower plastic bag use. Around 59.7 billion pieces of sachets yearly, more than 50% of all unrecyclable residual waste discarded are branded wastes, and only 10 companies are responsible for 60% of all the branded wastes. Solid wastes generated from business and commercial establishments are transported using large trucks or containers. Solid wastes are recycled into useful raw or finished products with the aid of technologies in recycling facilities. Recycling improves the management of municipal solid wastes and helps reduce the volume of waste disposed of in the landfill and divert it to recycling companies (Palomar et al. 2019).

Table 1. *Different studies conducted related to solid waste management (SWM) practices in the Philippines.*

Year	Focus of the Study	Findings
2010	Recyclable collection trends, and best practices	Best practice is the LGU-led recycling of waste or voluntary collection. (Antonio 2010).
2010	Reduce, Reuse and Recycle (3Rs) and Poverty Reduction	LGUs own initiatives and schemes that achieve success with the participation of the informal sector (Chiu 2010).
2019	Synergy in the urban solid waste management system	Constructed system dynamics model demonstrated the synergy in the urban solid waste management system (Tinio et al. 2019).
2019	Waste management through recycling	Recycling improves the management of municipal solid wastes and reduces the volume of waste disposed in the landfill (Palomar et al. 2019).
2019	Waste assessments and brand audits	Organic wastes comprise more than 50% of generated wastes. Around 59.7 billion pieces of sachets yearly and more than 50% of unrecyclable residual waste discarded are branded wastes (Rola 2019).

Policy Development and Implementation

Atienza (2011a) reviewed the waste management system being implemented in RA 9003 and the constraints of its implementations (Table 2). Policies on SWM were passed from 1938 to 2001. LGUs were responsible for waste collection and disposal under their jurisdictions. The lack of cooperation within the community, lack of infrastructure, and politics are the main factors that resulted in the failure of past governance. RA 9003, also known as the Ecological Solid Waste Management Act of 2000 is already behind schedule. There are still open and controlled dumpsites. However, there are also success stories at the municipal level such as information, education, and communication (IEC) campaigns that were conducted, and low-cost and local technologies that were utilized. In 2019, the ocean plastic waste problem and policy development were studied. No comprehensive statistics to quantify the production of plastic waste are available, but only data on the generation of solid waste by geo-political area, waste sources and broad forms of solid waste (GAIA 2019). In small communities, coasean solution or coase theorem is practiced by small commercial sectors that move private institutions toward the marketing of eco-friendly, recyclable, and organic goods. Recent study was conducted by Austin et al. (2018) on the “plastic-eating enzyme” as a solution to plastic accumulation.

Table 2. *Different studies conducted related to policy development and implementation in the Philippines.*

Year	Focus of the Study	Findings
2011	Review of the waste management system	Passed policies from 1938 to 2001. Factors on the failure of the past government measures include the lack of cooperation of the community, lack of infrastructure, and politics. Implementation of RA 9003 is behind schedule although there are success stories focused on IEC campaigns and use of low-cost and local technologies (Atienza 2011a).
2019	Ocean’s plastic waste problem and policy developments	"Coasean solution" for small commercial practices by small communities. Private institutions moved towards the marketing of "eco-friendly," "recyclable" and "organic" goods. Some LGUs banned the use of plastics. Discovery on the “plastic-eating enzyme”as a solution to plastic accumulation was reported (Austin et al. 2018 as cited in Dockrill 2018). Opportunity costs and economic implications to clean the oceans are needed to consider (Abueg 2019).

Waste Integration, Conversion and Recovery

Studies on waste integration, conversion, and recovery in the Philippines were the focus of research of Terazono et al. (2015), Figueroa (2014), and Shakeri et al. (2012). Shakeri et al. (2012) examined recycled plastic as aluminum laminate trimming relative to environmental physical stressors as barrier material (Table 3). Figueroa (2014) conducted characterization of temperature profile in solid waste decomposition for harnessing thermal energy. Solid waste management and practices studied by Terazono et al. (2015) focused on analyzing the gold recovery process on e-waste as conducted by informal recyclers.

Waste Electrical & Environmental Equipment (WEEE) contains both valuable and toxic substances. The field survey at the informal recycling site showed that valuable metals like gold (Au) and other toxic substances such as lead (Sb) were present in the soil at the informal recycling site. Aside from the recovery process, there are also studies on the waste decomposition processes. The temperature profile of the heat absorber output was close to that of the landfill waste temperature profile and no sign of full organic decomposition after 27 days due to high temperature. In the aspect of waste recycling, organoclay (OC) increased the permeability of water vapor and thermal insulation products. Recycled Plastic Aluminum (RPA) with 10% OC had the most effective thermal insulation. Fourier Converted Infrared (FTIR) has demonstrated that all pristine RPAs, independent of thickness and lightweight plastic aluminum laminate trimming (FPALT) particle size, are environmental stress cracking (ESC) resistant (Terazano et al., 2015).

Table 3. *Different studies related to waste Integration, conversion, and recovery in the Philippines.*

Year	Focus of the Study	Findings
2012	Recycled plastic aluminates relative to environmental physical stresses as barrier material	Organoclay impregnation (OC) increased the permeability of water vapor and thermal insulation products. Recycled Plastic Aluminum (RPA) with 10% OC is the most effective thermal insulation RPA. Fourier Converted Infrared (FTIR) demonstrated that all pristine RPAs, independent of thickness and lightweight plastic aluminum laminate trimming (FPALT) particle size, are environmental stress cracking (ESC) resistant (Shakeri et al. 2012).
2014	Characterization of temperature profile in solid waste decomposition for harnessing thermal energy	Temperature profile of the heat absorber output was close to the waste temperature profile of the landfill but initially improved during the first 100 hours with temperature of 37°C. No sign of full organic decomposition after 27 days observed mainly due to high temperature. The 15.24 x 0.0127-m (long x diameter) heat absorber configuration recovers the waste energy from the decomposition of organic waste (Figueroa 2014).
2015	Recovery process and evaluation of the recycling site	WEEE contains valuable and toxic substances but has markets in metal scrap. Valuable compounds and toxic substances have been distributed in the soil at the informal recycle site (Terazono et al. 2015).

Electronic Wastes Recycling and Management

Carisma (2009) and Alegre and Borcena (2010) analyzed the e-waste policy gap and ICT waste (Table 4). Carisma (2009) focused on the dynamics between drivers and barriers surrounding the end of life of electronics while Alegre and Borcena (2010) examined the poor collection and recycling ecosystems in the growing volume of ICT waste. De Guzman (2014) conducted SWOT analysis and developed a tool for decision making to effectively evaluate the e-waste management systems. Perkins et al. (2014) explored the problems encountered in e-waste recycling practices. And found out that informal recyclers captured almost 75% of e-waste and were exposed to hazards. In 2016, a remarkable increase in the number of e-waste studies were conducted focusing on e-waste management practices and recycling including process flows and informal recycling sites (Morallo 2016; Yoshida 2016, et al., Alam 2016). University policies and practices on e-waste management including the perception of undergraduate students on e-waste management practices were checked out (Ancheta 2017; Antolo et al. 2017; Boas et al. 2016). Electronic wastes recycling and management focusing on the university e-waste management and practices were studied by Morallo (2016). Primary step to address the increase in mobile phones by estimating the volume of waste was conducted by Galang and Ballesteros (2017). Electronic waste management and the impact to human health and the environment were examined by Celestial et al., (2018). Manota (2019) also conducted research that analyzed the characteristics of e-waste and recoverable electronic components.

Table 4. *Different studies on electronic wastes recycling and management in the Philippines.*

Year	Focus of the Study	Findings
2010	E-waste focusing on ICT waste	Personal computer (PC) and mobile telephones increased from 79 million in 1991 to 2010. Household PC ownership pegged at 5.9% in 2006 but steadily increased (Alegre & Borcena 2010).
2014	E-waste recycling practices	E-waste generated an increase and was compounded by illegal exportation and inappropriate donation of electronic equipment. Only 25% of e-waste is recycled in formal recycling centers with adequate worker protection. Policy frameworks existed but not effectively applied (Perkins et al. 2014).
2014	Management tool in evaluating e-waste management system	In the SWOT analysis, strengths include setting a standard for the mobile phone industry if a take-back scheme will be implemented. As a weakness, educating the people with the proper disposal of e-waste particularly for End-of-Life mobile phones. Opportunities involve strengthening regulation from the government. For threats, improper disposal of End-of-Life mobile phones by users, secondhand shops and repair shops should be prioritized. Highest factor comes from the weakness focused on educating the consumers on the disposal of mobile phones (De Guzman 2014).
2016	E-waste management	Storage is the most used mode of disposal. Concern on the accumulation due to discarded cellular phones compared to discarded laptops and personal computers (Alam 2016).
2016	University e-waste management practices	E-wastes were being stockpiled in a room and other hazardous e-wastes on the grounds. No policy on e-waste management and no

		established collection of e-waste available (Morallo 2016).
2016	Recycling processes of e-waste, process flows, and informal recycling sites	End-of-life cathode ray tube (CRT) TVs and computer monitors contribute to e-waste. Formal facility has automated processing equipment for CRTs. CRT glass handled by informal sectors was illegally disposed (Yoshida et al. 2016).
2016	University policies and practices on e-waste management	Institutions cannot afford to throw it away because of the health and environmental hazardous wastes. Correct identification and characterization of electronic waste led to a considerable level of practice in waste disposal (Boas et al. 2016).
2017	University e-waste management practices	More than 40kg of e-waste generated monthly during the first semester. Main campus partially implemented the e-waste practices. Needs improvement to minimize e-waste by implementing policies (Ancheta 2017).
2017	Perception, and practices of students on e- waste and management practices	Disposal methods were mainly trashing e-waste and marginalized recycling options. Common recycled e-wastes were appliances and phones intended for making other devices (Antolo et al. 2017).
2017	Estimation of mobile phone wastes	Attempted to address the increase in mobile phones by estimating the volume of waste mobile phones based on sales. Mobile phones from 2010 to 2021 with a calculated accuracy of 99% (Galang & Ballesteros 2017).
2018	E-waste management and impact to human health and the environment	No official data on the quantity of e-waste generated but e-waste generators who consume electrical and electronic equipment and discard are divided into corporate consumers and private or household consumers (Celestial et al. 2018).
2019	Characteristics of e-wastes and recoverable electronic components	Disassembling and dismantling to disintegrate e-waste and categorize. E-wastes are 79% made of plastics, metals, and glass and 21% are electronic materials. Eighty percent are retrieved electronic components that are still functional and usable (Manota 2019).

Technology on Waste Management

The technologies and waste management projects of model cities in the Philippines show promising results (Table 5). Cebu City and Davao are pioneering the Waste to Energy project under Public and Private Partnership (PPP). In this project, combustible solid waste materials are converted into usable energy to cease the exponential increase of solid wastes and decrease dependency on the non-renewable source of energy. Metro Manila, Iloilo City, and Davao City focused on *estero* and coastal rehabilitation and integration of solid waste management and landfill with material recovery facilities to reduce solid waste pollutants and recover the reusable and economically important waste. These five cities created ordinances and policies based on RA 9003. Examples are the 'No Plastic Policy' and 'Program on Urban Ecosystems and Practices for the Abatement of Pollution through Networking and Management of Toxic Substances and Hazardous Wastes'. These two ordinances are intended to serve as a guide for government and other major stakeholders in developing policies, as well as implementing integrated management approaches that will enhance public awareness to lessen environmental degradation and pollution in urban areas.

Table 5. *Different technologies developed related to waste management.*

Technology	**Description**	**Highlights**
Bulb Eater Machine 2011	Machine to break down light bulbs into smaller elements	Feeding the bulbs into the Bulb Eater to contain the chemical content of light bulbs and keep hazards. Packages for safe shipping where the chemical will be extracted and recycled for other uses (Tuazon 2011).
Centralized Gravity-Driven MRFs 2013	An in-house unit that wastes is segregated during down-passage through gravity force.	Incoming wastes at the Eco-Center are screened and sorted at the MRF, processed, and recorded daily. Wastewater generated in the MRF is treated in the leachate treatment facility. Designed to increase material recovery, efficiency of waste diversion and use of low-cost technologies including a gravity-driven facility (Hanuschke et al. 2013).
Refuse-Derived Fuel (RDF) 2016	Converts energy from non-recyclable as a substitute to traditional fuel	RDF is used as alternative fuel raw material for cement co-processing of cement plants. Each ton of RDF used in cement plants replaces 600kg of coal. Compacting of RDF after shredding and the densification of discharged waste after sorting allows the 40% reduction on the number of trucks leaving the platform compared to a pure waste transfer station (Sapuay 2016).
Vermicomposting 2016	Aerobic production of compost using earthworms and	Used horse manure from more than 20 racehorse farms in Batangas produces 4.5 tons/day of vermicast

	biodegradable materials.	registered by the Fertilizer and Pesticide Authority with more than 200,000 stakeholders (Guerrero III 2016).
Plastic Waste Bricks 2017	Recycled polyethylene terephthalate (PET) plastic waste to produce precast concrete	Development of a modular composite brick made with multilayer single-use plastic waste operational in 15 cities running 15 machines. GreenAntz produced 225,000 bricks (The Global Plastics Alliance 2017).

Role of Science, Technology, and Innovation on R&D of Waste Management

Science, technology, and innovation (STI) are viewed as sources of new knowledge, products, and services that benefit the economy and society (PSA 2018). STI is still globally accepted as the main driver of transformation towards an inclusive and environmentally sustainable economy and advancement of a country (NAST 2016; Mans et al. 2015). STI is emphasized in the Sustainable Development Goals (SDG) as the key in delivering and implementing all the other 17 SDGs and bridge the gaps in between through its central role as the main driver of transformation (UNCTAD 2019). STI in waste management is a key utility service in which its linkage to 12 of the 17 SDGs is unquestionable (Rodic-Wiersma & Wilson 2017). The role of STI especially in the process of shifting from a linear economy (produce, use, decompose) towards a circular economy in the Philippines can never be overemphasized (DOST 2018). STI is crucial in processing water waste, e-waste, solid waste, and energy waste products to be utilized for product generation (Celestial 2018).

Information to describe the extent of implementation of STI on the issue of resource sustainability and waste management are limited. Other countries, particularly first world countries have successfully utilized the roles of innovator from STI in waste management towards sustainability (Ion & Gheorghe 2014). In the Philippines, sectors from agriculture, industry, services, and businesses are the focus for leveraging and promoting STI (NEDA 2017). The waste sector was not given emphasis neither mention at all in the report on STI in the Philippine Development Plan (PDP) 2017-2022 since its implementation. Nonetheless, all these sectors generate waste. The increase in the utilization of STI in agriculture is a product of the government's focused efforts on Negosyo Centers, entrepreneurship, and other institutions that offer business. Research and development funding was prioritized based on the commercial viability and marketability of the R&D outputs (NEDA 2018). While waste management has been known to be costly and complex activity, NEDA admits in its most recent socioeconomic report (SER) in 2018 that the country's science, technology, and innovation (STI) sector is detached from its development efforts and reforms are necessary to link the two (NEDA 2018). However, the government continued to underinvest in R&D. The Philippines overall R&D expenditure remained at 0.14% of its gross domestic product (GDP) in 2015. It was very low relative to expenditures of its ASEAN peers on R&D. NAST also added that the country's STI is burdened by archaic legal, financial, and administrative rules and practices which stifle R&D, innovation, and productivity and hindered the Philippines in achieving sustainable development practices and poverty reduction (NAST 2016).

On the national level, the Department of Environment and Natural Resources-Environmental Management Bureau (DENR-EMB), in coordination with the National Solid Waste Management Council (NSWMC), mainstreamed the establishment and operation of alternative technologies, including waste-to-energy technologies to address the increasing volume of waste brought by rapid urbanization. In 2019, DENR Secretary Roy A. Cimatu signed DENR Administrative Order No. 2019-21 which details the guidelines governing waste-to-energy facilities for integrated management of municipal solid wastes (EMB 2019). NAST also proposed a program geared towards utilizing STI for waste management. This program institutes measures that balance development and environmental concerns and harness technological advances to deal with climate change, disaster risk reduction or management, biodiversity conservation especially in the mapping of pollution sources and risks, vulnerable communities and ecosystems, and land use and cover change (NAST 2016). On the local scale, waste management innovations were reported in Bais City, Negros Oriental (Paul et al. 2012). The municipal solid waste management system was enhanced by the LGU and waste avoidance strategies were established. The needed infrastructure to manage waste more efficiently was also provided. In turn, this resulted in the establishment of a central waste management center (WMRC) which integrates composting plant, material recovery facility, wastewater treatment facility, and engineered landfill with a Bentonite enhanced clay-liner, the first in the Philippines. The application of a base clay-liner instead of a synthetic liner was chosen to lessen investment cost and allow a project implementation in line with the available equipment and municipal funds. With this project, the recovery of organic waste increased to more than 30% of the collected waste that is mainly processed at the municipal composting facility. Consequently, the disposal of organic waste decreased significantly. The new WMRC is now recognized for its local expertise, its innovative technologies and environmental monitoring and early warning systems. The crucial role of good governance is further confirmed by a few municipalities, namely, Los Banos, Laguna, Bagumbuhay, Quezon City, and Caloocan City which displayed excellent SWM practices through strong political will. Among the SWM success stories recorded include the cities of Suralla Cluster in South Cotabato, Albuquerque Cluster in Bohol, including the privately managed being utilized by LGUs such as in Navotas and Rodriguez Rizal. These cities conducted rigorous IEC campaigns and adopted low-cost and local technologies (Atienza 2011). Private sector enjoined in waste management geared towards CE using STI. The Director of the Global Centre for Technology, Innovation and Sustainable Development at the UNDP emphasized giving incentives to companies in making their products more accessible to people (Romero 2019). The Chief Advisor of the Japan International Cooperation Agency highlighted that the government should recognize the efforts of private entities by providing a non-fiscal incentive or reward (Romero 2019).

SUMMARY AND CONCLUSION

Based on the trend, Solid Waste Management research in the Philippines was mostly focused on plastic recycling followed by studies on electronic waste (e-waste). There were also studies on organic waste decomposition which leans toward producing thermal energy. Majority of SWM studies lean towards investigating best plastic recycling practices since plastic pollution received global attention for its disturbing effects on the society, economy, and environment (Otoma & Castillo 2013; Senoro & Saiyari 2012; Antonio 2010; Chiu 2010). In the Philippines, there were eight studies that examined e-waste issues: health protection of e-waste workers (Terazono et al. 2015; Perkins et al. 2014), creation of decision-making tools for e-waste management, knowledge, attitude, and practices in e-waste management in schools and universities (Ancheta 2017; Antolo et al. 2017; Boas 2016; Morallo 2016), and monitoring and controlling of e-waste through the use of neutral networks (Galang & Ballesteros 2017).

Overall, there is an apparent scarcity of the actual research to describe the extent of the use of Science, Technology and Innovation on waste management in the Philippines. Waste management is seemingly not a direct concern of STI in the PDP 2017-2022, the actual roadmap that the country follows and is not clear now for its efforts related to waste management. However, as demonstrated in some cases presented, efforts and initiatives in the country are not absent in terms of acknowledging science and technology as enablers of innovation for waste management. It seems that the government needs to re-institutionalize the National Government –Local Government Unit scheme for waste management programs. The government must also strengthen its partnership with private sectors by giving incentives to institutions promoting Circular Economy so that they become motivated to create innovative products that are geared towards this. Science, Technology and Innovation should also be ingrained in the educational and governance system of the country to make it easier for technological advances to find their application in matters related to waste management. Undoubtedly, the Philippines needs more efforts to increase the generation of new knowledge and to facilitate the transformation of knowledge into productive uses. Stronger advocacy and political will are needed. Increased technological literacy through education and training, better policies, and more investments are imperative. Meanwhile, the identified research gaps include partnership with key government offices and recyclers to establish official baseline e-waste data, development of best dynamics and test the link between informal and formal processors, development of appropriate technology beneficial among informal e-waste recyclers, and impact of illegal transboundary movement of e-waste. Community mobilization and the participation and high political will of the LGU officials are also factors to successful solid waste management. The creation and implementation of policies is an important element in dealing with different concerns in the governance of solid waste. Planning and operation of solid waste management should be implemented through the application of good governance that promotes the application of different stakeholders. Likewise, awareness campaigns, and the promotion of innovative and appropriate technologies are vital to achieve a sound waste management system in the country.

REFERENCES

Abueg, L. (2019). A survey of the ocean's plastic waste problem, and some policy developments of the Philippines.

Alam, Z. (2016). The assessment of the e-waste management generated from cellular phones, laptops, and personal computers in the Philippines, Manila. *Journal of Science, 9, 27-42.*

Alegre, AG., & Borcena, PG. (2010). Philippines – Foundation for Media Alternatives (FMA). Retrieved 6 June 2011 from Global Information Society Watch website: http://www.giswatch.org/sites/default/files/gisw2010countryphilippines_en.pdf.

Ancheta, A.C. (2017). Electronic Waste Management Practices and Its Extent of Implementation: A Case of an Academic Institution. Southern Leyte State University, Sogod, Southern Leyte, Philippines. Journal of Educational and Human Resource Development, 57, 51-57.

Antolo, M., Concemino, LM., Emano, VY., & Macabecha, GC. (2017). Electronic waste management of undergraduate students: The Case of a Philippine Sectarian University.

Antonio, LC. (2010). Study on recyclables collection trends and best practices in the Philippines. Policies Southeast East Asia.

Atienza, V. (2011)a. Review of the waste management system in the Philippines: Initiatives to promote waste segregation and recycling through good governance. *In* Kojima & Michida (Eds.) Economic integration and recycling in Asia: An Interim Report.

Atienza V. (2011)b. Inter-Municipal cooperation on solid waste management in ASEAN: The case of the Philippines. Available online at https://www.ide.go.jp/library/English/Publish/Download/Ec/pdf/201903_ch05.pdf.

Austin, H., Allen, M., Donohoe, B., Rorrer, N., Kearns, F., Silveria, R., Pollard, B., Dominick, G., Duman, R., El Omari, K., Mykhayklyk, V.., Wagner, A, Michener, W., Amore, A.., Skaf, M, Crowley, M.., Thorne, A, Johnson, C., Woodcock, HL., McGeehan, J, & Beckham, G. (2018). Characterization and Engineering of a Plastic-degrading Aromatic Polyestarase. PNAS May 8, 2018 115 (19) E4350-E4357; first published April 17, 2018; https://doi.org/10.1073/pnas.1718804115.

Boas, C., Dionisio, CA., Madriñal, AC., & Sim, TJ. (2016). E-Waste Management: An Assessment of Implementing Practices in Selected Engineering Universities of Metro Manila.

Carisma, B. (2009). Drivers of and Barriers to e-Waste Management in the Philippines. (Master's thesis). Lund University, Sweden. Retrieved from: http:lup.lub.lu.se/studentpapers/record/1511085/file/1511091.pdf

Castillo, AL., & Otoma, S. (2013). Status of solid waste management in the Philippines. Available online at https://www.jstage.jst.go.jp/article/jsmcwm/24/0/24_677/_pdf.

Celestial, RG. (2018). E-waste management in the Philippines. DOI: 10.13140/RG.2.2.17965.74728.

Chiu, AS. (2010). The 3Rs and poverty reduction in developing countries. Asia Resource Circulation Policy Research Working Paper Series. Hayama, Kanagawa: *Institute for Global Environmental Strategies (IGES).*

De Guzman, F. (2014). Evaluation of E-waste management in the Philippines using AHP-SWOT methods: A case study on the mobile phone take-back scheme. Retrieved from https://animorepository.dlsu.edu.ph/etd_bachelors/2728.

Department of Science and Technology [DOST]. (2018). Waste resources to an inclusive circular economy. Available online at http://www.dost.gov.ph/knowledge resources/news/49-2018/1443-waste-resources-to-inclusive-circular-economy.html.

Environmental Management Bureau [EMB]. (2019). National solid waste management report. Available online at https://emb.gov.ph/wp-content/uploads/2019/08/National-Solid Waste-Management-Status-Report-2008-2018.pdf.

EMB. (2019). DENR AO 2019-21. Available online at https://emb.gov.ph/w content/uploads/2020/01/Guidelines-Governing-Waste-To-Energy-WtE-Facilities-for-the Integrated-Management-of-Municipal-Solid-Wastes.pdf.

Figueroa, A.M.I. (2014). Characterization of temperature profile in solid waste decomposition to demonstrate potential for harnessing thermal energy. *In* 2014 International Conference on Humanoid, Nanotechnology, Information Technology, Communication and Control, Environment and Management (HNICEM). pp. 1-4. IEEE.

Galang, M.G., & Ballesteros, F Jr. (2018). Estimation of Waste Mobile Phones in the Philippines using Artificial Neural Networks.

Geissdoerfer, M., Savaget, P., Bocken, NMP., & Hultink, EJ. (2017). The circular economy- A new sustainability paradigm? *Journal of Cleaner Production*. 143.

Guerrero III, RD. (2016). Vermicomposting in the Philippines. Philippines: National Academy and Technology.

Hanuschke, K., Batomalaque, A., Sanches, L., Romallosa, AR., & Paul, J. (2013). Evaluation of Waste Diversion Effects through a Low-Cost, Gravity-driven Waste Sorting Plant in San Carlos City, Philippines.

Ion, I., & Gheorghe, FF. (2014). The innovator role of technologies in waste management towards sustainable development. *Procedia Economics and Finance*. 8: 420-428. DOI: 10.1016/S2212-5671(14)00109-9.

Luttenberger, LR. (2020). Waste management challenges in the transition to a circular economy- Case of Croatia. *Journal of Cleaner Production,* 120495. DOI: 10.1016/j.jclepro.2020.120495

Manota, April Cathy S. (2019). Reducing Electronic Waste from Households thru Recovery for Re-use.

Mans, N., Ingeborg, N., Francouse, R., Enrico, G., & Micheal, S. (2015). The role of science, technology, and innovation policies to foster the implementation of sustainable development goals (SDGs). *European Commission*. DOI: 10.2777/615177.

Marquez, AJC, Rutkowski, EW. (2020). Waste management drivers toward a circular economy in the global south- The Colombian case. *Waste Management*. 110: 53-65. DOI: 10.1016/j.wasman.2020.05.016

Morallo, Narcisa T. (2016). Carbon Monoxide and Hydrocarbon Contains of Motorcycles: Metro Dumaguete, Philippnes.

National Solid Waste Management Council [NSWMC]. (2016). National solid waste management strategy 2012-2016. Available online at https://nswmc.emb.gov.ph/wp content/uploads/2016/07/NSWM-Strategy-20122016.pdf.

National Academy of Science and Technology [NAST]. (2016). Harnessing science a technology for poverty reduction and sustainable development. Available online: https://www.nast.ph/index.php/13-news-press-releases/249-harnessing-science-and technology-for-poverty-reduction-and-sustainable-development.

National Economic and Development Authority [NEDA]. (2017). Socioeconomic reports. Available online at http://www.neda.gov.ph/wp-content/uploads/2018/03/SER-Chap-14_as-of-May-8.pdf.

NEDA. (2018). Socioeconomic reports. Available online at http://www.neda.gov.ph/wp-content/uploads/2019/09/SER-2018_Posted-Chapters.pdf

Palomar, AAU., Sundo, MB., Velasco, PP., & Camus, DRD. (2019). End-of-pipe waste analysis and integrated solid waste management plan. *Civil Engineering Journal 5*(9): 1970-1982.

Paul, J., Buquiran, M., & Libradilla, ET. (2012). Waste management innovations in Bais City, Philippines. Available online: https://www.researchgate.net/publication/329923254_Waste_management_innovations_in_Bais_City_Philippines.

Perkins, D., Mckie, B., Malmqvist, B.., Gilmour, S, Reiss, J., Woodward, G. (2014). Environmental Warming and Biodiversity-Ecosystem Functioning in Freshwater Microcosms: Partitioning the Effects of Species Identity, Richness and Metabolism.

Philippine Statistics Authority [PSA]. (2018). Philippine statistics development program. Available online at http://www.psa.gov.ph/philippine-statistical-system/psdp/program/2018-2023.

Romero, D., Cordova-Pizarro, D., Aguilar-Barajas, I., & Rodriguez, CA. (2019). Circular economy in the electronic products sector: Material flow analysis and economic impact of cellphone e-waste in Mexico.

Rola, AC. (2019). Managing Plastic Waste and the Role of Local Governments. National Academy of Science and Technology Philippines (2019). Available online at https://www. nast. ph/index. php/downloads/category/151-sinlge-use-plastics.

Rodic-Wiersma, L., & Wilson, DC. (2017). Resolving governance issues to achieve priority sustainable development goals related to solid waste management in developing countries. *Sustainability*. 9:404. DOI: 10.3390/su9030404.

Sauvé, S., Bernard, S., Sloan, P. (2016). Environmental sciences, sustainable development, and circular economy: Alternative concepts for trans-disciplinary research. *Environmental Development*. 17: 48-56.

Sapuay, GP. (2016). Resource recovery through RDF: Current trends in solid waste management in the Philippines. *Procedia Environmental Sciences.* 35: 464-473.

Senate Economic Planning Office [SEPO]. (2017). Philippine solid waste in a glance. Available online at https://www.senate.gov.ph/publications/SEPO/AAG_Philippine%20Solid%20Wastes_Nov2017.pdf.

Senoro, D., & Saiyari, D. (2012). Study of Recycled Plastic Aluminates Relative to Environmental Physical Stresses as Barrier Material.

Shakeri, H., Shoeybi, M., Salvacion, JL. (2012). Experimental analytical simulation method in landfill geomembrane liner design. *International Journal of Environmental Science and Development*. 3(2): 161.

Terazono, A. Murakami, S., Abe, N., Inanc, B., Moriguchi, Y., Sakai, S., Kojima, M., Yoshida, A., Li, J., Yang, J., Hung Wong, M., Jain, A., Kim, I., Peralta, G., Lin, C., Mungchareon, T., and Williams, E. (2005). Current Status and research on e-waste issues in Asia. *J. Mat. Cycles Waste Management. 8, 1-12.*

Tinio, MMR., Rollon, AP., & Moya, TB. (2019). Synergy in the Urban Solid Waste Management System in Malolos City, Philippines. *Philippine Journal of Science*. 148(1): 73-97.

The Global Plastics Alliance. (2017). Marine Liter Solution. Available online at Philippines GreenAntz Plastic Waste Bricks: https://www.marinelittersolutions.com/projects/philippines-greenantz-plastic-waste bricks/.

Tuazon, J. (2011). 'Bulb Eater' helps curb toxic waste. Available online at GMA News Online: https://www.gmanetwork.com/news/scitech/content/224659/bulb-eater-helps-curb-toxic waste/story/.

United Nations Conference on Trade and Development [UNCTD]. (2019). A framework for science, technology, and innovation policy reviews: Harnessing innovation for sustainable development. *United Nations.* Available online at https://unctad.org/en/PublicationsLibrary/dtlstict2019d4_en.pdf.

Yoshida, A., & Terazono, A. (2010). Reuse of secondhand TVs exported from Japan to the Philippines. Waste Management. 30: 1063-1072. DOI: 10.1016/j.wasman.2010.02.011.

Yoshida, A., Terazono, A., Ballesteros, FCJ., Nguyen, D., Sukandar, S, Kojima, M., & Sakata, S. (2016). E-waste recycling processes in Indonesia, Philippines, and Vietnam: A case study of cathode ray tube TVs and monitors. *Resources, Conservation and Recycling*. 106:48-58. DOI: 10.1016/j.resconrec.2015.10.020.