Sustainable Asset Valuation Tool

MATERIALS MANAGEMENT INFRASTRUCTURE

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Sustainable Asset Valuation Tool: Materials management infrastructure

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Abbreviations and Acronyms

BAU	business as usual
C&D	construction and demolition
CBO	community-based organization
CEC	Commission for Environmental Cooperation
CDM	Clean Development Mechanism
CO_2e	carbon dioxide equivalent
DRS	deposits-refund system
EC	European Commission
EEA	European Environment Agency
EfW	energy from waste
ELV	end-of-life vehicle
EMF	Ellen MacArthur Foundation
EPA	Environmental Protection Agency
EPR	Extended Producer Responsibility
EU	European Union
e-waste	electronic waste
FAO	Food and Agriculture Organization of the United Nations
FIT	feed-in tariff
GHG	greenhouse gas
GIB	Green Investment Bank
GIZ	Deutsche Gesellschaft für Internationale Zusammernarbeit
GLT	Gum Litter Taskforce
GPP	green public procurement
IFC	International Finance Corporation
IISD	International Institute for Sustainable Development
IRRC	Integrated Resource and Recovery Centres
ISWM	Integrated Sustainable Waste Management
KCC	Khulna City Corporation
MRF	material recycling facilities

MSW	municipal solid waste
NGO	non-governmental organization
NIMBY	Not In My Backyard
OECD	Organisation for Economic Development and Co-operation
O&M	operations & management
PAYT	pay-as-you-throw
PET	polyethylene terephthalate
PPP	polluter pays principle
PRN	packaging recovery notes
PVC	polyvinyl chloride
RCRA	Resource Conservation and Recovery Act (RCRA), 1976
RDF	refuse-derived fuel
RPS	renewable portfolio standard
SAWIC	South African Waste Information Centre
SPREP	Secretariat of the Pacific Regional Environment Programme
TPD	tonnes per day
TDS	transported to disposal site
UK DEFRA	UK Department for Environment, Food and Rural Affairs
UK DECC	UK Department of Energy and Climate Change
UN	United Nations
UNEP	United Nations Evironment Programme (UN Environment)
UNSD	United Nations Statistics Division
VOC	volatile organic compound
WEEE	Waste Electrical and Electronic Equipment
WHO	World Health Organization
WtE	waste-to-energy

1.0 Light Screening

Definition of sustainable materials management infrastructure	The International Institute for Sustainable Development (IISD, 2017) defines sustainable infrastructure as assets that optimize value for money economy-wide and promote sustainability throughout their lifetime. As a result, sustainable materials management infrastructure is defined as infrastructure that allows the reduction of waste material generation through promoting recovering, reusing and recycling materials, ultimately reducing disposal and landfilling. As a result, this is infrastructure that is, across a variety of activities and stages in materials management, effective and efficient when considering environmental, economic and social performance indicators. As part of materials management, we refer to waste as materials that have no further use and are to be discarded through an appropriate waste management system. This is in line with the given definition from the UN Statistics Division (UNSD), whereby waste is "materials that are not prime products for which the generator has no further use in terms of his/her own purposes of production, transformation or consumption, and of which he/she wants to dispose" (UNSD, n.d.). We find that existing literature does not directly define sustainable material management infrastructure, even though literature on sustainable waste management exists. Literature refers to sustainable waste management systems as systems that "must address all technical (infrastructure) and governance aspects to allow a well-functioning system that works sustainably over the long term" (Wilson et al., 2015). Green material management infrastructure also respects the hierarchy of waste management, prioritizing prevention over disposal (United Nations Environment Programme [UNEP], 2011). Sustainable material management infrastructure may extend into the realm of the circular economy, whereby infrastructure supports material recovery and reuse streams, minimizing end-of-life generation (Ellen MacArthur Foundation [EMF], 2016). In the case of this review, infrastructures involved in solid waste management systems are considered. This review will look into management systems addressing the following types of materials, the majority of which are considered municipal solid waste (MSW) (UNEP, 2011): • Electronics • Hazardous materials • Plastics and packaging • Healthcare waste • Food and other organics • Biomass and agricultural materials • Metals
Types of grey and green material management infrastructure	The literature demonstrates varying characteristics of what constitutes sustainable material management infrastructure. The challenges to differentiate between grey and green infrastructure include the complexity of material management systems and the lack of coherent and widely recognized sustainability indicators (Cetrulo et al., 2018; Ikhlayel, 2018). Grey and green material management infrastructure can be categorized generally as below (Annepu, 2012; Bogner et al., 2007; Wilson et al., 2015). Grey: • Single-stream material management systems • Management systems with no material recovery • Waste incineration without energy recovery • Unmanaged and unregulated landfills • Unmanaged and unregulated waste dumping Green: • Sorting facilities • Recycling and recovery facilities • Composting facilities • Waste to energy (WtE) (i.e., anaerobic digestion, landfill gas capture, incineration with energy recovery, refuse-derived fuel) • Sanitary landfills

Indicators used to measure performance	The common indicators that measure sustainability performance are: • Resource consumption rate (material use, kg per capita) • Waste material collected and transported to disposal sites (TDS) • Waste material per capita (MSW per capita, kg per year) • Waste material generated (tonnes per day [TPD]) • Recycling rate (percentage of total MSW generated) • Percentage of waste collected and disposed of in sanitary landfill (or proper landfill) • Waste material captured by the system (percentage MSW generated handled completely by the system) • Carbon dioxide avoided per amount of waste material diverted from landfilling A number of waste material management concepts may incorporate these indicators to evaluate the performance of waste infrastructure and management systems. The main types of assessment that include indicators for assessing the sustainability of material management are integrated solid waste management (ISWM), environmental impact assessments, cost–benefit analyses, material flow analysis, energy analysis, life-cycle assessment and urban metabolism (Allesch & Brunner, 2014; Pincetl et al., 2012).
Shortcomings of business as usual (BAU)	Unregulated or poorly managed material management systems may result in waste material processing that has many negative externalities (Wilson et al., 2015). Negative impacts of BAU scenarios are categorized below. **Environmental** Unsustainable material management infrastructure and systems can cause bad air and groundwater pollution. Unregulated dumpsites can contain hazardous waste materials like heavy metals and carcinogens (Ferronato et al., 2017). Additionally, the waste sector contributed to 1.6 billion tonnes of carbon dioxide equivalent (CO_2e) emissions in 2016 alone (World Bank, 2016). Poorly sited and regulated infrastructure can also contribute to marine litter (Sheavly & Register, 2007). **Economic** Degradation of natural resources will increase the stress on resources that are already being depleted as the world population reaches 9.8 billion in 2050 (UN Department of Economic and Social Affairs, 2019). Economic costs of grey infrastructure may include impacts from degraded environmental aesthetics and ecosystems, causing losses in the tourism, shipping and fishing industries of up to USD 1.3 billion in the Asia-Pacific alone (UNEP, 2014). The Love Canal pollution in Niagara Falls, New York, resulted in cleanup costs of USD 259 million (1993–1996 dollars) (U.S. Environmental Protection Agency [US EPA], 2019b). **Social** Public health impacts arise from waste pollution. Informal waste industries resulting from market failure to provide necessary waste management services have increased informal workers' exposure to hazardous substances in addition to providing poor working and health conditions (Afon, 2012). The increase of disease and pathogenic burden may catalyze outbreaks, like the pneumonic plague in Surat, India (Ghosh, 1998). A study in Brazil demonstrated that informal recycling of waste at home increased the likelihood of high blood lead levels in children (Ferron, de Lima, Saldiva, & Gouveia, 2012). The lack of regulation has also led to the exploitation of child labourers in the informal waste sector (Adama, 2014). Furthermore, the siting of grey infrastructure has created strong citizen perspectives against waste infrastructure, leading to Not-In-My-Backyard (NIMBY) movements, some with environmental justice implications (Rootes, 2009).
Advantages of green infrastructure investments	Green material management infrastructure contributes to a number of economic, social and environmental advantages. It is important to note that green material management infrastructure does not eliminate all the negative externalities of grey material management infrastructure, but it alleviates the problems significantly. Distinct advantages include resource efficiency, energy savings, greenhouse gas (GHG) emissions reduction, green job creation and equity, and poverty reduction. **Environmental** Practising resource recovery can reduce the carbon footprint in product manufacturing. Recycling one tonne of aluminum and steel can save 95 per cent or 14,000 kWh and 642 kWh of energy, respectively (Stanford Recycling Center, n.d.) Organisation for Economic Development and Co-operation (OECD) countries have the potential to have net carbon dioxide savings of 286,906,000 tCO_2e under an ideal scenario of recycling, composting and incineration with energy recovery (Vogt et al., 2015). Recycling and reusing can bring significant resource savings as well, such as in the glass glazing recycling industry (Farel, Yannou, Ghaffari, & Leroy, 2013). Recycling material reduces the need to mine and utilize virgin materials. **Economic** The economic cost of waste material management varies across countries but represents a large expenditure for local governments. Annual cost ranges from USD 0.9 per capita to USD 137 per capita (Fellner, 2014). Sustainable material management infrastructure can lead to greater cost savings in the long run by avoiding unnecessary clean-up costs, and it may lead to benefits from energy and resource recovery. A case study on reconstruction and renovation in Poland showed that recycling construction and demolition (C&D) material can save more than half of input costs in the long run (Sobotka & Sagan, 2016). **Social** Green jobs can emerge from introducing sustainable practices linked to infrastructure procurement. The recycling industry in Brazil, China and the United States accounts for 12 million jobs. Projections under a green economy scenario predict a 10 per cent increase in employment within the waste material industry by 2050 (UNEP, 2011). In Jordan, recycling centres and waste collection have employed refugees and provided training (Deutsche Gesellschaft für Internationale Zusammenarbeit [GIZ], 2015). Sustainable material management infrastructure implementation also provides the opportunity to formalize working conditions. In yet another job-generating recycling centre, the formalization of informal waste pickers would yield a net gain of USD 16,000 in Islamabad (Gower & Schröder, 2018).

Risks of infrastructure	Infrastructures are relatively permanent upon their implementation and can be hard to retrofit in the future. Risks of grey and green infrastructure investment vary depending on the policy environment for waste management and the maturity of waste management systems. However, common risks have been identified below. **Grey Waste Infrastructure Risks** **Regulatory** Trends reveal that countries are shifting toward sustainable waste infrastructure. In Morocco, sanitary landfill disposals increased from 10 per cent in 2008 to 53 per cent in 2016. Grey landfills are not being employed (Kaza et al., 2018). **Market** Markets have been shifting toward greener waste infrastructure and systems. In the commodities market, China's National Sword Policy has decreased the value of mixed paper and plastic scraps because of the world's reliance on recyclable exports (Read & Vinogradova, 2018). **Technical** Grey waste infrastructure does not keep the waste material hierarchy in mind and cannot respect the environmental, economic and social aspects. In the long run, WtE facilities that are not sustainable are cost-inefficient (McAnulty, 2019). **Social Pressure** The public has responded negatively to poor waste management because of the externalities they have to face. Civic movements have risen up in opposition to grey or poorly managed infrastructure being sited close by, from Hong Kong to Ireland (Ferreira & Gallagher, 2010; Lam, 2018). **Green Infrastructure Risks** **Regulatory** The policy and regulation environments for green infrastructure are changing and creating uncertainties for infrastructure implementation (APSRG, 2012; Winne et al., 2012). At the same time, some countries do not have a proper regulatory framework to provide suitable conditions for green infrastructure (Srivastava et al., 2015). **Market** Market risks may include the lack of feasibility of small-scale operations, the risk of merchant facilities and volatile prices for commodities (Engel et al., 2016). There is also a risk in waste processing technologies crowding out one another, such as discussions over recycling versus WtE (Luthra, 2017). Revenue from resource recovery can be volatile, and there is variability on willingness to pay among consumers (Kaza et al., 2018; Wilson et al., 2015). **Technical** There are inherent technical risks to different facilities and methods of recovering, processing and reusing material. Recovered polyethylene terephthalate (PET) materials in plastics have a relatively high risk of polyvinyl chloride (PVC) contamination (Hopewell et al., 2009). Contaminated recyclables are priced lower than "clean" materials (World Bank Group, 2018). **Social Pressure** Similar to grey infrastructure, green waste infrastructure may receive social backlash on the perceived negative externalities of waste infrastructure. The authorities may fail to communicate the benefits of sustainable waste infrastructure, and the public may address green waste infrastructure with skepticism (Achillas et al., 2011). Since infrastructure can be politically sensitive, there are risks associated with projects' final feasibility.
Obstacles and opportunities of green infrastructure implementation	**Obstacles**: • Waste generation is increasing, but so is the complexity of waste types, requiring more specific solutions to deal with increasingly complicated waste streams (UNEP, 2011). • The data gaps and the lack of standardized waste indicators create challenges in monitoring and measuring sustainability (Kaza et al., 2018; UNEP, 2011). • Infrastructure implementation involves many stakeholders and requires coordination across governments, landowners, residents and more (Ehlers, 2014). • Different levels of maturity of waste management legal framework across countries mean that the feasibility of different types of sustainable infrastructure will differ (Monier et al., 2017). • The waste management industry already has a huge financing gap. Infrastructure, including operation and technological, transportation, storage and processing aspects, are costly (Kaza et al., 2018). • The lack of a technology track record for the feasibility of sustainable waste infrastructure and technology may deter new investors (NERA, 2015). **Opportunities**: • Growing population and demand for material management services: Waste material generated by cities is expected to increase to 3.40 billion tonnes annually by 2050 (Kaza et al., 2018). • Sustainable material management is increasingly recognized as a solution to climate mitigation (C40 Cities, 2016). • Increased awareness of plastic recycling and circular economy practices within the private sector (EMF, 2013). • Green public procurement is increasingly popular for governments and the private sector, with the European Union investing EUR 17.5 billion in circular activities in 2016 (European Commission [EC], 2019d). • Export bans and tighter waste import policies call for more local solutions (Hook & Reed, 2018).

Policy interventions

The growth in waste generation over the last decade mandates the implementation of policies addressing all stages of the UNEP (2011) waste management pyramid.

Policies can be categorized as legislative measures, command-and-control, market instruments and incentives, information-based instruments, support mechanisms and voluntary mechanisms (Wilson et al., 2015; Taylor et al., 2012). Legislative measures include the polluter pays principle (PPP), which holds polluters financially responsible for costs of damage.

Legislative measures

Waste prevention
The Basel Convention is an international treaty that regulates the transboundary movement of hazardous waste (United Nations Environment Programme & Basel Convention, 1989).

Public health
Barbados lays out waste management responsibilities and regulations via three separate pieces of public health legislation: Health Services (Disposal of Offensive Matter) Regulations (1969), Health Services (Nuisances) Regulations (1969) and Health Services Act, 2002.

Environment
Under the Environmental Protection Act of 1983, Switzerland's waste management relies on the PPP. The prevention, collection, treatment, recovery and disposal of waste are outlined under the Federal Act on the Protection of the Environment, 1983.

Energy
The Clean Energy Jobs Act and Clean Energy Act were passed in Maryland and Washington, D.C., respectively. The bills recognize WtE measures as renewable energy sources, which boosts the market for this infrastructure (Clean Energy DC Omnibus Amendment Act of 2018, Clean Energy Jobs in Maryland 2019).

Command-and-control approaches:

Waste directives
The Resource Conservation and Recovery Act (RCRA) (1976) was passed in the U.S. Congress to regulate hazardous waste materials from "cradle-to-grave."

Waste targets
The city of San Francisco announced a zero-waste vision by 2020 and has passed a series of material bans since 2006, including Styrofoam and plastic bags (Kaza et al., 2018).

Portfolio standards and feed-in tariffs (FITs)
China has successfully deployed a FIT for waste incineration. Future plans are to incorporate WtE in China's renewable portfolio standard (Zhao et al., 2017).

Zoning
In Ghana, the Town and Country Planning Ordinance delegates land-use functions. The ordinance identifies waste sites and does not allow dumping (Town and Country Planning Department, 2011).

Bans or phase-outs
Chile became the first South American country to ban commercial businesses from using plastic bags nationally in August 2018 (Gaia Discovery, 2018).

Market instruments and incentives:

Taxes and tax differentiation
Catalonia, Spain, charges higher landfill and incineration fees for waste without recovery (R4R, 2014).

Landfill tipping, gate fees and pay-as-you-throw (PAYT)
Estonia increased its annual gate fees by 700 per cent over 10 years in 2006, as a result of increased technical standards and operation costs. The high landfill fees are effective in reducing waste material (European Environment Agency [EEA], 2009).

Tax credits
Brazil introduced tax credits, regulated under Decree n. 7,619/2011, for the use of solid residues in manufacturing processes in 2010. Taxpayers are able to receive credits from utilizing plastic, paper and paper cartons, glass, iron and steel, copper, nickel, aluminum, lead and zinc (Da Silva, 2015).

Tradable pollution rights
Packaging recovery notes (PRNs) are issued in the United Kingdom, encouraging producers to reduce packaging waste. PRNs are also tradable (Valpak, 2019).

Policy interventions (continued)	**Deposits-refund system (DRS)** *South Australia launched container deposit legislation in 1977, contributing to high container return rates. In 2017–2018, return rates were 78.1 per cent (South Australia EPA, n.d.).* **Pay-as-you-throw (PAYT)** *PAYT initiatives in Portland, Oregon, and Falmouth, Maine, have increased rates from 7 to 35 per cent and 21 to 50 per cent, respectively (UNEP, 2011).* **Information-based instruments** **Labelling certification** *Architettura Naturale (ANAB) is a certification scheme that certifies sustainable building products and furniture (Ecolabel Index, n.d.).* **Targeted information provision** *The South African Waste Information Centre (SAWIC) is a hub for waste material management information in South Africa, producing data on waste material generation and processing (SAWIC, 2005).* **Naming and shaming** *A civil society movement in the Philippines conducted a waste inventory in six cities and called out the top three brands that contributed to non-recyclable waste (Libson, 2019).* **Ratings** *The GreenCo E-waste Recycler Rating System was created in Chennai, India, to help industries transition to a sustainable e-waste recycling system (Sustainable Recycling Industry, 2018).* **Support mechanisms** **Capacity building** *Kenya's National Environmental Management Agency set up an e-waste recycling network in Kenya and other East African markets (Modak et al., 2015).* **Financing** *New Zealand established the Waste Minimisation Fund in 2015 to promote waste reduction and recovery, which includes financing waste infrastructure (New Zealand Ministry for the Environment, n.d.).* **Knowledge sharing** *The Japan International Cooperation Agency Research Institute (JICA-RI) has helped various African countries promote waste infrastructure. They have also published a report on solid waste management gaps in Africa (Yamamoto, 2019).* **Intragovernmental coordination** The EC adopted the Circular Economy Action Plan in 2015 to transition to a circular economy. The plan focused on "closing loops" in material streams and increasing the recycling rate (EC, 2015b, p. 21). **Voluntary mechanisms** **Voluntary regulations** *Singapore launched the Singapore Packaging Agreement in 2007. It is a voluntary initiative established between the government, industry and non-governmental organizations (NGOs) with a goal of reducing packaging waste (Singapore National Environment Agency, 2019).* **Covenants and negotiated agreements** *The Gum Litter Taskforce (GLT) was launched in 2007 in Ireland as an agreement between the chewing gum industry and the public to reduce gum litter. Strategies include funding of websites and media campaigns (Fingal County Council, 2018).* **Civic regulation** *The Shanghai Rendu Ocean NPO Development Center, an NGO, launched its Coastal Waste Civilian Monitoring Project in 2014, which detects and monitors marine waste (China Development Brief, 2019).* **Extended producer responsibility (EPR)** *South Africa has successfully implemented EPR programs, including metal packaging. The government mobilized supporting legislation, and the private sector mobilized appropriate technology to recover up to 72 per cent of metal cans across the country (Wilson et al., 2015).*
Actors involved	• **Governments**: National regulators play a crucial role in establishing a framework to approach the implementation of sustainable waste infrastructure. Regional and city authorities are responsible for waste management systems, especially for MSW. • **Private sector**: The sector provides technological solutions and can adopt sustainability measures in manufacturing processes. • **Academia**: Data, research and development gaps can be addressed with the help of research and academic institutions to reinforce the implementation of sustainable waste management solutions. • **NGOs**: NGOs keep actors accountable for their sustainability commitments. • **Individuals**: Consumer base drives demand for sustainable measures in goods and services. Individual inputs are also important in the provision of appropriate waste management services.

Existing sustainability standards	Material management infrastructure and systems may choose to adopt waste standards. The standards are applicable to sustainability practices in either industrial processes, regional waste management practices or waste infrastructure operations. Material management standards: • ASTM International: waste standards for local governments • International Organization for Standardization: waste standards for different waste types and packaging standard • Global Reporting Initiative: waste disclosure standards for the private industry • EnergyStar: waste benchmarking and reporting • POLITICO: circular economy index for countries in the European Union, based on the European Union (EU) circular economy monitoring framework.

2.0 In-Depth Review: Sustainable waste infrastructure

2.1 Definition of Waste Materials

Before discussing sustainable material management infrastructure, it is important to address the definition of waste materials. Waste material is defined in many ways in different contexts. Broadly speaking, waste materials are substances that we do not have remaining uses for. In their Global Waste Management Outlook report, UNEP adopts the concept that waste is "unwanted or discarded materials, rejected as useless, unneeded or excess to requirements" (Wilson et al., 2015). The UNSD has adopted a similar view, where waste is made up of "materials that are not prime products for which the generator has no further use in terms of his/her own purposes of production, transformation or consumption, and of which he/she wants to dispose" (UNSD, n.d.). The definition also extends to include waste material generated during extraction, processing and consumption of products but excludes recycled or reused residuals (UNSD, n.d.)

In literature, waste material has been discussed with regard to the legal definition assigned by national, regional or international frameworks. However, national definitions of waste material vary based on the level of economic and cultural development, as evident in the EU (Twardowska, 2004). The EU defines waste material with this variation in mind, using flexible terms for waste material as "any substance or object which the holder discards or intends or is required to discard" (Directive 2006/66/EC, 2008). Likewise, international frameworks have recognized the lack of a commonly shared definition of waste material. The Basel Convention refers to waste material as "substances or objects which are disposed of or are intended to be disposed of or are required to be disposed of by the provisions of national law" (UNEP & Basel Convention, 1989).

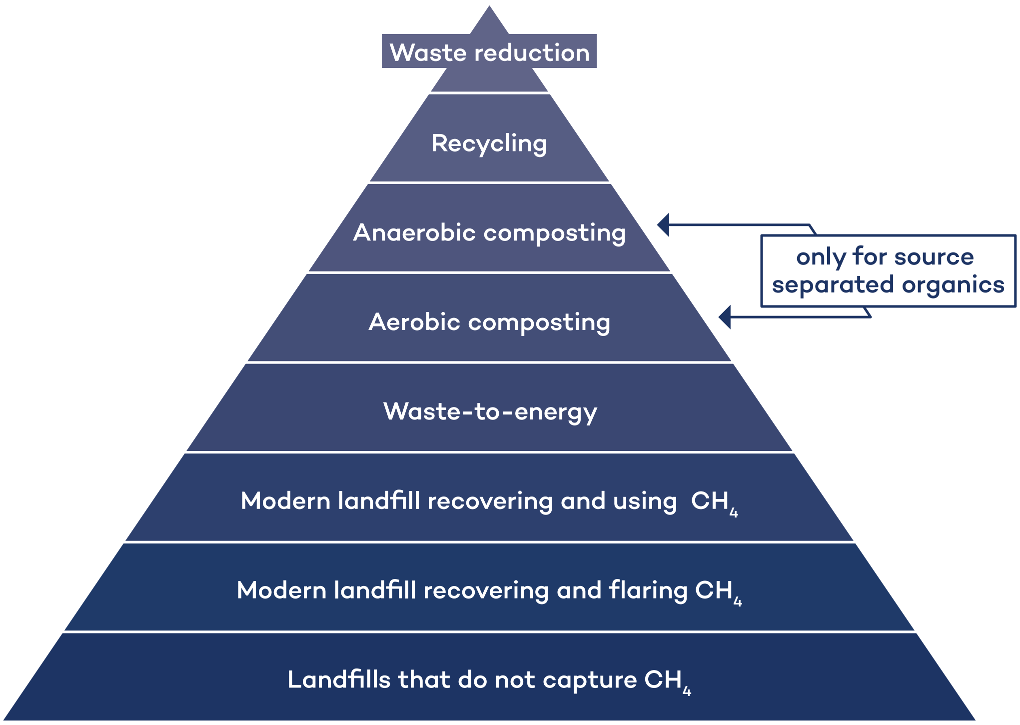
For the purpose of this review, IISD aligns with UNSD's definition of waste material, while keeping in mind that national definitions of waste material, and subsequently the rigour of material management designs, do vary. However, IISD will view waste material with regard to its material stream because a material management approach is more robust. The review will also be concentrating on solid materials. Under the RCRA, the United States categorizes solid waste as "any garbage, refuse, sludge from a waste treatment plant, water, supply treatment plant, or air pollution facility and other discarded material" (RCRA, 1976). While the RCRA applies "solid waste" to solids, liquids, semisolids or contained gases, IISD will focus on materials in the solid state.

This review will address different types of solid materials, some of which are hazardous. The common categories of solid materials include electronics, plastics and packaging, organic waste, healthcare, biomass and agricultural, metal and vehicular materials (UNEP, 2011). A large proportion of waste materials can be categorized as MSW, which is made up of discarded materials from residential, industrial, commercial, institutional, C&D and municipal services (Hoornweg & Bhada-Tata, 2012). MSW is featured heavily throughout this review.

2.2 Definition of Sustainable Material Management Infrastructure

There is no clear definition of "sustainable material management infrastructure." IISD defines sustainable infrastructure as assets that optimize value for money economy-wide and assets that promote sustainability throughout their lifetime (IISD, 2017). Literature on "sustainable waste management" exists, much of it aligning with the concept of ISWM (UN Human Settlements Programme [UN Habitat], 2010; Wilson et al., 2015). The ISWM approach was proposed as a framework that engages stakeholders, waste material system elements and sustainability aspects based on the principles of equity, effectiveness, efficiency and sustainability (Van de Klundert & Anschutz, 2001). UN Habitat simplifies the concept of ISWM to three systems: the physical system, sustainability aspects and stakeholders (UN Human Settlements Programme, 2010). Sustainable infrastructure comes into play with the interaction between the technical aspect of physical material management systems and sustainability.

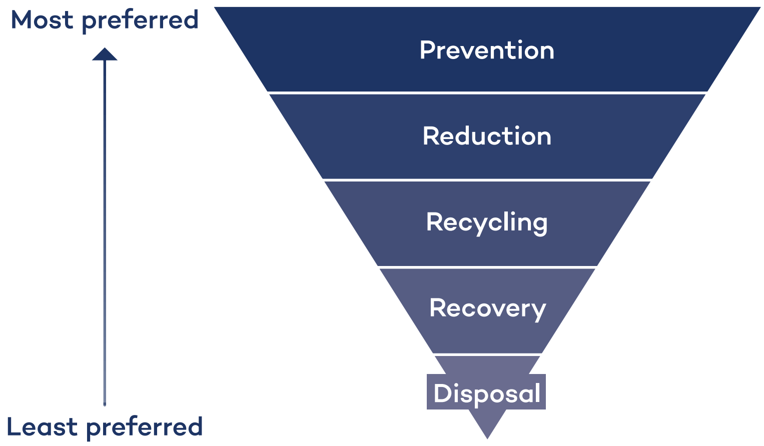
Figure 1. Hierarchy of waste management developed by Columbia University



Source: Reprinted with permission from Earth Engineering Center, n.d.

Columbia University's hierarchy of sustainable waste management gives more clarity on what sustainable material management infrastructure entails (Earth Engineering Center, n.d.). According to the hierarchy, sustainable material management infrastructure consists of technical and physical material treatment aspects that minimize the amount of discarded material generated at the end of the material stream (see Figure 1). The concept builds on the waste management hierarchy, which prioritizes prevention over disposal with the objective of reducing end-of-use materials (UNEP, 2011). UNEP refers to sustainable material management as "the efficient use of material resources to reduce the amount of waste produced and, where waste is generated, to managing it in a way that actively contributes to the economic, social and environmental goals of sustainable development" (Wilson et al., 2015).

Figure 2. The waste management hierarchy



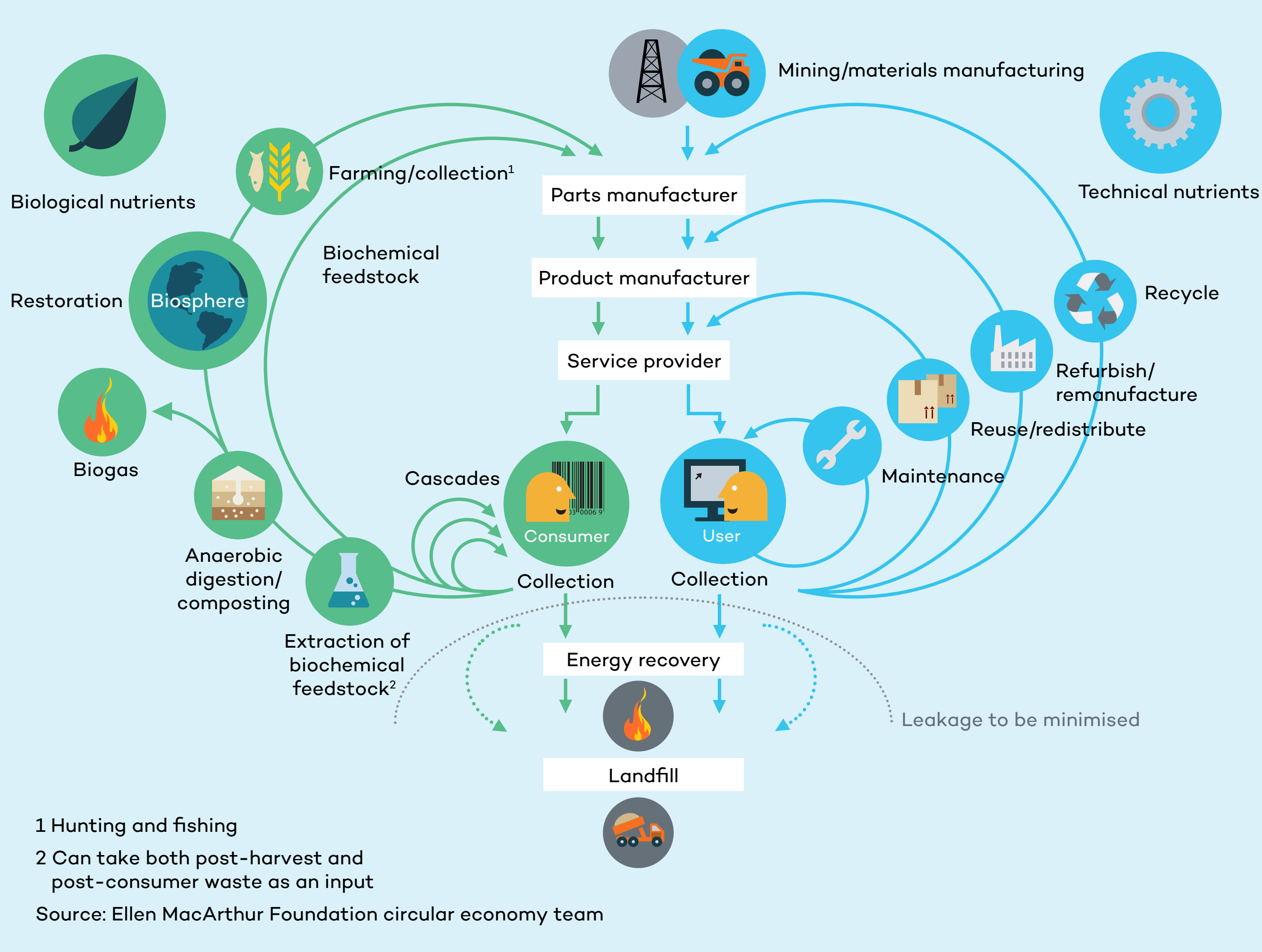
Source: Reprinted with permission from UNEP, 2011 (p. 294).

In recent years, the movement toward a circular economy has gained ground. The shift to promoting clean growth is largely driven by population growth and increased demand for finite resources (McKinsey CBE, 2016). The EMF released its first report on the circular economy in 2013, stating that:

> A circular economy is an industrial system that is restorative by intention and design. In a circular economy, products are designed for ease of reuse, disassembly and remanufacturing – or recycling – with the understanding that it is the reuse of vast amounts of material reclaimed from end-of-life products, rather than the extraction of new resources, that is the foundation of economic growth. (EMF, 2013)

In a circular economy, goods will be turned into resources for other goods or services, effectively "closing the loop" in industrial ecosystems and reducing waste (Stahel, 2016). Other definitions of circular economy have aligned closely with this definition, having additional perspectives of integrating value-added links within the system (EC, 2015a; Potting, Hekkert et al., 2017).

Figure 3. A circular economy design



Source: Reprinted with permission from EMF, 2013.

Sustainable material management infrastructure plays an important role in reducing overall end-of-use material generation. A circular economy requires a shift in systems thinking to incorporate linear, circular and performance economies. Sustainable material management infrastructure is at the core of transitioning into a closed-loop industrial process (Stahel, 2016). A successful transition requires investment into the proper infrastructure while engaging the correct stakeholders and material processes of a circular economy (EMF, 2013). The European Commission actively promotes green public procurement (GPP) as a key action in implementing circular economy design (EC, 2019b). In the material stream, there are multiple entry points for sustainable infrastructure to create a circular economy system, putting the waste hierarchy (see Figure 2) to use and maximizing material efficiency.

2.3 Green Versus Grey Infrastructure

Material management involves the collection, treatment and disposal of materials (Kaza et al., 2018). The BAU scenario does not consider the material management hierarchy (UNEP, 2011). This review will assess grey versus green infrastructure based on end-disposal versus non-end-disposal infrastructure. Generally, end-disposal or "grey" material infrastructure includes unsanitary landfills (like dumping), open burning and incineration without energy recovery (Annepu, 2012).

On the other hand, green infrastructure is spread throughout the material management hierarchy, mainly throughout the recycling and recovery processes. There are three main categories of sustainable material management infrastructure: material recovery infrastructure, energy recovery infrastructure and sanitary landfills (Annepu, 2012). The latest reports on the circular economy further explore the improvement of the efficiency of circular economies and sustainable material management infrastructure via the employment of data collection and artificial intelligence monitoring (EMF, 2016, 2019).

Material Recovery Infrastructure

Material recovery infrastructure includes facilities that can sort, recycle and/or recover materials. The four main types of recovery facilities are material recovery facilities, composting facilities, sorting facilities and recycled content manufacturing (remanufacturing) facilities. These amenities have different functions, even though they generally fall under the recovery process. For the recovery and recycling process to be complete, sorted materials need to be processed as inputs for recycling or recovery to occur.

SORTING FACILITIES

Sorting facilities are facilities that collect and differentiate waste materials by category. Generally, sorting facilities accept, sort and store recyclables before transporting the waste materials somewhere else (Zero Waste Scotland, 2019). Nothing is processed on-site. Sorting technology may be used, which includes magnetic separation, mechanical sorting and screening (Surrey County Council, 2017).

MATERIAL RECOVERY FACILITIES

Also known as "dirty MRF" or "mixed waste processing facilities," the waste received in material recovery facilities are known to be highly contaminated (GBB Inc., 2015). These facilities may separate and process the waste feedstock that usually comes from single waste streams or has mixed recyclates. The output will be processed in a different facility. Sorting technology may be used.

COMPOSTING FACILITIES

Composting facilities take organic waste, which includes food waste, lawn and tree clippings, and wood waste. Composting facilities usually employ aerobic composting or biological decomposition methods. This method relies on microbes to oxidize carbon to break down the material. The process may produce products like fertilizer (Annepu, 2012). This can be deployed on household, community or scaled-up levels.

RECYCLING FACILITIES

Recycling facilities are infrastructures that support recycling, which may pertain to collecting, sorting and processing materials (Institute for Local Government, 2015). Processing recycling materials involves the remanufacturing or repurposing of the original product. Plastic can be remanufactured into pellets to produce recycled plastic goods. Recycled paper or boxes may be used for producing cardboard (Institute for Local Government, 2015).

OTHERS

Community recycling centres, waste transfer stations and MRFs are usually co-located. These serve communities and local authorities (Surrey County Council, 2017).

Energy Recovery Facilities

Energy recovery facilities generate energy from residual waste material (end-of-use material that cannot be recycled) (European Bioplastics, 2015). The terms "energy recovery from waste," "energy from waste (EfW)" and "waste-to-energy (WtE)" can be used interchangeably. Residual waste undergoes a variety of processes, mostly thermal treatments like combustion and pyrolysis, to obtain energy. Other processes may include gasification, anaerobic digestion and landfill gas recovery (UK Department of Energy and Climate Change [DECC] & UK Department for Environment, Food and Rural Affairs [DEFRA], 2014). Energy recovery falls under the "recovery" scope of material management, which is preferred second-to-last in the waste material management hierarchy. In the past, energy recovery facilities have been loosely regulated and have earned a reputation for being dirty. However, recent regulations in Europe impose stricter regulations and guidelines for energy recovery facilities' efficiency and emissions (UK DECC & UK DEFRA, 2014).

ANAEROBIC DIGESTION

Anaerobic digestion uses microorganisms to break down organic materials in an environment without oxygen. The process will produce biogas, a mixture of methane and carbon dioxide, and digestate or residual slurry, which can be used as fertilizer (UK DEFRA & UK DECC, 2013). The biogas can be used to produce heat and electricity.

REFUSE-DERIVED FUEL (RDF)

RDF may be considered a "pre-treatment" fuel, produced directly from combustible, mostly unsegregated municipal waste (Global Alliances for Incinerator Alternatives, 2013). Different standards may apply to RDF production processes in countries. The fuel output may be used to generate heating or electricity (UK DECC & UK DEFRA, 2014).

PYROLYSIS

Pyrolysis uses technology to convert biomass to obtain combustible gases, oil or solid fuel (i.e., char or carbon) (UK DEFRA & UK DECC, 2013). The process is defined as "the thermal decomposition of lignocellulosic derivatives under inert condition in oxygen-deficient environment" (Zaman et al., 2017).

GASIFICATION

The gasification process converts solid waste into gas products. Solid waste undergoes several stages of transformation, including drying, pyrolytic decomposition, gasification reaction and secondary gaseous reactions as needed (Waldheim, 2018). The gas product can generate electricity used for heating (UK DEFRA & UK DECC, 2013).

COMBUSTION

Direct combustion or incineration is used to generate heat and electricity directly. They may be combined with heat and power systems (UK DEFRA & UK DECC, 2013).

LANDFILL GAS RECOVERY

Landfill gas is produced by the decomposition of organic material, producing a 50/50 mixture of carbon dioxide and methane (U.S. EPA, 2019a)—GHGs that contribute to climate change. Landfill gas may be captured and used to generate energy.

Sanitary landfills are "controlled disposal of waste on the land" that reduce the negative effects of solid waste in the area significantly (UNEP, 2005). Proper sanitary landfilling should incorporate different waste management strategies that isolate landfill wastes from the environment until the wastes are deemed biologically, chemically and physically safe (UNEP, 2005). The basic requirements of sanitary landfills include partial hydrogeological isolation, waste disposal and final restoration planning, permanent and regular control, and planned covering (Massachusetts Institute of Technology, n.d.). Sanitary landfills are still regarded as unfavourable, as they accommodate end-use waste material. Even though sanitary landfills and their corresponding technology are widely deployed in developed nations, the cost of this infrastructure may be a challenge for developing nations (UNEP, 2005)

The different types of infrastructure and their impacts on material flow stages are outlined below. To assess the social, environmental and economic aspects of the material management infrastructure, the infrastructure is assigned a tick mark if it makes a positive impact. Negative aspects of the infrastructure do not negate the rating.

Table 1. The functions (sort, recycle, recover, disposal) of each material management infrastructure based on a literature review of facilities that are in construction or in operation. Two arrows signify "high function," whereas one arrow signifies "low or moderate function." The table also indicates whether each material management infrastructure accounts for social, environmental and economic aspects. The assignments of the arrows and tick marks are qualitative, based on available literature.

Infrastructure	Sort	Recycle	Recover	Disposal	Social	Environment	Economic
Material Recovery							
Sorting facilities	↑↑	↑↑	↑↑		✓	✓	✓
Material recovery facilities	↑	↑	↑↑		✓	✓	✓
Composting facilities	↑		↑↑		✓	✓	✓
Recycling facilities	↑	↑↑	↑↑		✓	✓	✓
Energy Recovery							
Anaerobic digestion	↑		↑		✓	✓	✓
RDF			↑				✓
Pyrolysis			↑		✓	✓	✓
Gasification			↑		✓	✓	✓
Combustion			↑				✓
Landfill gas recovery			↑			✓	✓
Sanitary Landfill				↑		✓	✓

2.4 Shortcomings of BAU Scenarios

As a consequence of unregulated or poorly designed material management systems, material management activities lead to increased GHG emissions, scarcity of natural resources, human health consequences, environmental degradation, economic loss, environmental justice concerns and poor labour standards. Grey material management infrastructures cause many environmental damages, as they perpetuate unsustainable material management practices. Some sustainable material management infrastructures cause similar negative externalities to grey infrastructures, but these externalities are alleviated.

The negative externalities of deploying unsustainable material management infrastructure are outlined below.

2.4.1 Environmental

Many negative environmental externalities result from poor material management, especially with unregulated dumping and poorly designed grey infrastructures. Pollution from leachates and hazardous materials leads to the degradation of natural resources like soil, air and water. Ecological consequences include human health effects, which are outlined in the social section.

Air pollution from unsustainable material management primarily comes from open burning or unregulated incineration facilities.

INCINERATION IN WUHAN, CHINA

In the 1990s, China faced increased demand for municipal waste disposal due to growing cities. Waste incineration resulted in the production of fly ash, dioxins and heavy metals (Wang et al., 2017). Toxic heavy metal emissions from the open burning of MSW in China increased from 4.04–715.38 tonnes to 10.76–1,790.70 tonnes from 2000 to 2013 (Wang et al., 2017). Another study found that 17 of 28 provinces in mainland China suffer from carcinogenic risks that exceeded the acceptable level (Zhou et al., 2018). These risks can be managed by deploying WtE incineration facilities with proper pollutant standards and monitoring services.

Groundwater pollution stems from unsanitary landfills. Most of these landfills do not undergo proper environmental impact assessments in relation to siting and health measures. In the past few decades, landfill-related disasters have occurred, resulting in huge economic and health costs. Most developed nations have adopted legislature and policies regulating landfills closely. However, many developing nations, especially low-income countries, still have weak regulations for landfills (Kaza et al., 2018).

LOVE CANAL LANDFILL IN 1977 AND OTHERS

Love Canal, an unfinished development project in Niagara Falls, New York, was converted into a hazardous waste landfill in the 1940s. From 1942 to 1953, around 21,000 tonnes of toxic chemicals were dumped in the area (Kleiman, n.d.). A myriad of health effects like epilepsy, asthma, birth defects and miscarriages surfaced in the neighbourhood in the 1970s. These health incidents set off a huge activism and cleanup effort in the United States, resulting in the creation of Superfund and stricter regulations on landfill sites. However, some countries have yet to catch up on adequate landfill regulatory practices. A review by Ferronato et al. (2017) shows that MSW open dumping is still a problem in developing countries, and heavy metal groundwater contamination is ongoing in Thailand (Nonthaburi), India (Mathkal), Malaysia (Sepang) and many other countries.

Solid materials generate a large amount of **GHG emissions**. In 2016, solid waste accounted for 5 per cent of the total global GHG emissions, or approximately 1.6 billion tonnes of CO_2e emissions (World Bank, 2016). This is in comparison with 1.3 billion tonnes of CO_2e or 2.8

per cent of national GHG emissions from the waste sector in 2005 (Bogner et al., 2007). Landfills and inefficient transportation also contribute to methane emissions, which result from the decomposition of organic matter (Kaza et al., 2018).

Poorly sited landfills, uncovered waste infrastructure and inefficient waste collection might result in the **accumulation of marine litter** (Sheavly & Register, 2007).

NEW ZEALAND'S FOX RIVER LANDFILL FLOODING

A 100-year flood washed thousands of tonnes of trash out from disused, uncovered landfill into the West Coast of South Island (Bazley, 2019). Waste was deposited into deep underwater canyons nearby. Landfills located in Small Island Developing States and other coastal cities are vulnerable to marine litter because of their proximity to the coast. Aquatic life is also affected by marine litter, particularly by plastic debris. Animals get entangled or trapped in plastic debris and accidentally ingest plastic items, which can result in death (Thevenon et al., 2014).

2.4.2 Economic

BAU scenarios will inherently result in long-term economic losses. These losses may be direct or indirect, depending on their impact and externality liability. Economic losses may stem from within-sector losses, increasing resource scarcity and cleanup costs from environmental damages and human health effects.

Resource use per person is increasing, driving **natural resource scarcity**. The world population is projected to reach 9.8 billion in 2050 (UN Department of Economic and Social Affairs, 2019).

EXTERNALIZING NATURAL RESOURCE SCARCITY ISSUES

On average, an EU citizen uses 16 tonnes of materials, generating 6 tonnes of waste (EEA, 2010). The growing demand for natural resources has externalized some of the environmental and social impacts associated with production. Currently, the EU imports 20 per cent of its resources (EEA, 2010). The Global Material Resources Outlook to 2060 projects that global material use will increase from 79 Gt in 2011 to 167 Gt in 2060. However, material intensity will decrease further from -1.1 per cent (1980–2017) to -1.3 per cent (2017–2060) (OECD, 2018). Iron, antimony and barytes will have increased supply risks in the OECD region by 2030 (OECD, 2018).

The tourism industry will be affected by degraded environmental aesthetics caused by open dumping and marine litter. Economic costs from grey infrastructure may degrade environmental aesthetics and ecosystems, causing losses in the tourism, shipping and fishing industries of up to USD 1.3 billion in the Asia-Pacific alone (UNEP, 2014).

TOURIST LOSS IN PALAU

A 2004 survey conducted by the Palau Office of Planning and Statistics (2004) found that 32 per cent of tourists choose to come to Palau, an archipelago in Oceania, because of its renowned natural environment. In 2006, Hajkowicz, Tellames and Aitaro (2006) predicted that the solid waste pollution on beaches in Palau and the loss of visual aesthetics from landfills might result in approximately USD 961,000 in losses per year.

Environmental pollution or degradation caused by grey waste infrastructure may result in **high environmental cleanup costs**.

LOVE CANAL POLLUTION

Environmental pollution resulting from unsustainable waste management infrastructure can be costly as well. The pollution from hazardous waste dumping in Love Canal, Niagara Falls, New York, surfaced after 11 years of dumping. Studies found dioxins, volatile organic compounds (VOCs) and semi-VOCs in leachate and groundwater sites (US EPA, 2019c). This resulted in a cleanup cost of USD 259 million (1993–1996 dollars) (US EPA, 2019b).

2.4.3 Social

Grey infrastructure gives rise to a number of social issues, usually as indirect impacts of waste management systems. Negative social externalities primarily occur within public health, the informal sector and environmental justice issues.

Public health impacts arise from waste pollution in the environment

LEAD IN BRAZIL

A study in Brazil demonstrated that informal recycling of waste at home and the low education levels of fathers increased the likelihood of high blood lead levels in children (Ferron et al., 2012). Children were also exposed to lead through lead-containing soil and dust caused by contamination of old informal dump and industrial processes close by. Lead exposure in children has been a long-standing problem in Brazil because of poor management and siting of disposal and processing sites of hazardous waste (Olympio et al., 2017). Lead exposure may impair neurocognitive development in children, with permanent effects (Olympio et al., 2017).

Informal waste workers are subjected to poor working conditions and health risks (Afon, 2012).

CHILD WASTE PICKERS IN NIGERIA

The informal industry results from market failure to provide necessary material management services. The lack of regulation has also created opportunities for child labourers to enter the material collection market in many places. In Nigeria, poverty and socio-cultural factors like religious arrangements have enabled the demand for child waste pickers (Adama, 2014). Child labourers enter the waste picking industry because they have the least social capital and thus are vulnerable to exploitation. They are found to operate at the municipal level (Adama, 2014). A 2012 survey of young male waste pickers in Lagos showed that they are exposed to high risk of insect stings, malaria attacks and wounds from sharp objects (Afon, 2012).

The siting of grey infrastructure has also created **strong citizen opposition** against waste infrastructure, leading to NIMBY movements (Rootes, 2009).

NORTH CAROLINA HOG LAGOONS

Grey infrastructure, like unregulated incinerators, uncovered landfills and poor waste regulations, may lead to disamenities in the surrounding neighbourhood, including the risk of disease, odour and visual pollution. In North Carolina, local storage of hog waste in uncovered lagoons comes at a high environmental cost. A recent lawsuit filed by neighbours against a hog farm resulted in a USD 50 million damage payment to the plaintiffs (Armental, 2018). Residents living in closed-in areas with >215 hogs/km^2 also have higher mortality rates due to anemia, kidney disease, septicemia, tuberculosis, and low birth weight in infants (Kravchenko et al., 2018).

From previous examples, we glean that the **burden of diseases and pathogens** is heightened by poor infrastructure and management for solid waste material (Epstein, 2015). Open landfills and dumps are unsanitary, thereby breeding pathogens and other diseases. These sites may house vectors that exacerbate the disease burden.

THE 1994 PNEUMONIC PLAGUE OUTBREAK IN SURAT, INDIA

Poor material management systems and sanitation were main causes of the pneumonic plague outbreak in Surat. Clogged drainage systems caused by rubbish and negligence resulted in water logging at the end of a flood (Ghosh, 1998). Rodents that lived throughout the city were vectors of the plague and contributed to the Surat outbreak. The outbreak resulted in approximately 50 deaths, the temporary exodus of 60 per cent of the city's population and an economic loss of INR 12 billion (Swamy, Vyas, & Narang, n.d.)

2.5 Advantages of Sustainable Material Management Infrastructure

In 2016, cities around the world generated waste material at the rate of 2.01 billion tonnes of solid waste per year, and this number is expected to grow to 3.40 billion tonnes by 2050 (Kaza et al., 2018). As the world population expands and rapid urbanization takes place, sustainable material management systems become increasingly important. Sustainable material management systems, and thus sustainable infrastructure, have to be deployed to prevent the negative externalities generated from the waste material industry.

Sustainable material management infrastructure outweighs grey infrastructure in many ways because sustainable infrastructure encourages the diversion of waste streams and introduces more efficient waste material processes. The strongest reasons to invest in sustainable waste infrastructure are: 1) green infrastructure avoids many of the negative, costly externalities generated by grey infrastructure over the project's lifetime and 2) sustainable material management infrastructure provides many environmental and social benefits that BAU scenarios do not provide.

2.5.1 Environmental

Environmental advantages of sustainable material management infrastructure centres on the efficient use of resources and material savings. For example, energy savings take place when materials are recycled because energy can be released and recovered through several production cycles, unlike recyclables in end-use waste systems (Denchak, 2016). Furthermore, sustainable waste infrastructure may reduce the pollution externalities outlined in the section above.

Green material management infrastructure can bring about **resource savings** via recycling. Recycling materials like paper, plastics and metal can reduce the virgin materials, water and energy that go into production processes. The Stanford Recycling Center demonstrated that recycling one tonne of aluminum can save 95 per cent or 14,000 kWh of energy production compared to producing the metal from scratch (Stanford Recycling Center, n.d.).

RECYCLING GLASS IN END-OF-LIFE VEHICLES (ELVS) IN FRANCE

Each year, France produces an average of 41 kg of glass per ELV, which amounts to 70,000 tonnes of glazing per year and 20,000 tonnes of replacement glass. The EU published a directive with the target to recover or reuse at least 95 per cent of ELV weight by 2015 through recycling (EU Directive 2000/53/CE, 2000). In a cost–benefit analysis conducted on ELV glazing recycling in France, the best-case scenarios demonstrated that the system would receive more economic benefits than cost from the 26-year benchmark onwards (Farel et al., 2013).

Sustainable material management infrastructure diverts the waste stream and introduces processes that **reduce the carbon footprint** of waste management systems. As outlined above, standing solid waste contributes to 5 per cent of global GHG emissions (World Bank, 2016).

IMPACTS OF SUSTAINABLE WASTE MANAGEMENT IN OECD COUNTRIES

Recognizing that the climate change mitigation potential of material management is high, this report looks into different material management strategies and assesses the different carbon reduction impacts. The analysis demonstrated that the status quo of waste management in OECD countries would lead to emissions of 66,358,000 tCO_2e. However, through increasing recycling, composting and incineration with energy recovery, the ideal scenario will lead to net savings of 286,906,000 tCO_2e in 2030 (Vogt et al., 2015).

2.5.2 Economic

Economic benefits from sustainable material management infrastructure are linked to cost savings through material recovery and by avoiding preventable social costs. When appropriate economies of scale are achieved, sustainable material management infrastructure may be more cost-effective and efficient in the long run.

As a result of sustainable material management infrastructure, resource recovery can lead to **input cost savings** in the long run. Reusing materials cuts down on the need to mine and process virgin materials and can reduce the pressure on resource scarcity as well.

REUSING AND RECYCLING C&D WASTE IN POLAND

A case study was conducted on a small reconstruction and renovation project in Krakow, Poland. Two scenarios on C&D waste management were evaluated: anthropocentric and ecocentric scenarios. In the anthropocentric scenario, waste was not separated, leading to a total cost of PLN 2,770,179. In the ecocentric scenario, waste was sorted by type and processed to be resold or reused. As a result, the total cost was significantly reduced to PLN 15,207 (Sobotka & Sagan, 2016).

The cost of waste management can be a significant burden to municipalities, who bear the brunt of the cost. Annual expenditure for waste management ranges from USD 0.9 per capita to USD 137 per capita, contingent on factors like waste generation, GDP per capita and maturity of the waste management system (Fellner, 2014).

WASTE MANAGEMENT IN BAHIR DAR, ETHIOPIA

Bahir Dar faces a challenge in maintaining financial sustainability for the operation of solid waste management systems. The BAU scenario has inefficient fee collection and poor mechanisms for recycling and reuse. Due to the expanding demand for material management services and their financial sustainability, the private waste company that operates in the city is constructing an Integrated Organic Waste Recycling Centre. The value added by this recycling infrastructure includes the production of biogas from organic waste, compost and charcoal. These will help create a sustainable value chain for recycling services and enable cross-subsidization of other waste services (Lohri et al., 2014).

Green material management infrastructure may also **create new market opportunities**. Co-benefits may arise from sustainable practices that have never previously been explored. For example, compost and energy production are new developments within the green material management sector, especially in regions with less-developed waste systems.

EARNING CARBON CREDITS FROM RECYCLING

In 2010, the Clean Development Mechanism (CDM) Executive Body approved a new small-scale technology known as AMS-III AJ Recovery and Recycling of Materials from Solid Wastes. This technology recovers and recycles high-density polyethylene and low-density polyethylene into plastic resin or intermediates. These will result in energy savings and reduced carbon emissions. The determined CO_2e emission factors for the production of aluminum and steel are 8.40 and 1.27 tCO_2/t, respectively (CDM, 2018, p. 18.).

2.5.3 Social

Sustainable waste infrastructure improves on a number of social aspects through co-benefit pathways. The first is creating additional jobs, especially in areas that do not have well-established waste management facilities and systems. Another pathway is through the formalization of the informal waste sector. Other than providing more job security, formalizing the waste sector also supports equity and reduces poverty.

Green jobs can emerge from sustainable material management systems. Current projections under a green economy scenario foresee a 10 per cent increase in employment for the waste industry by 2050 (UNEP, 2011).

MEETING THE DEMAND FOR WASTE SERVICES IN JORDAN

The influx of refugees into Jordan has overwhelmed the waste material processing capacity of many municipalities. As a solution, recycling facilities have been established to deal with waste material generation and to provide employment opportunities. GIZ has helped establish a waste collection and recycling centre in Jordanian municipalities and refugee camps. These centres have helped train and employ 22,000 people by 2018. In the Zataari refugee camp, over 1,000 tonnes of materials were recycled (GIZ, 2015).

Informal waste picking and recycling services provide jobs to many individuals and can have large economic impacts. In Buenos Aires, 40,000 waste pickers contribute to USD 1.78 million per year, approximately 0.05 per cent of the city's GDP (Medina, 2008). **Formalized working conditions** will improve labour conditions and economic opportunities for marginalized communities.

INTEGRATED RESOURCE AND RECOVERY CENTRES (IRRCS) IN ISLAMABAD, PAKISTAN

In 2014, the first pilot IRRC was set up in Islamabad, with the capacity to process waste from 3,000 households. The centre collects, sorts and recycles materials. Organic material remains in the centre to be reused as chicken feed and compost. Fertilizer is also produced from chicken manure. The IRRC model applies to communities as well as informal settlements, generating jobs and income. A cost–benefit report shows that the centre costs USD 25,308 to operate annually and earns USD 41,895 in return (Gower & Schröder, 2018).

3.0 Risks to Project Financing, Operations and Management

3.1 Grey Infrastructure

REGULATORY

Material management systems vary across different countries and regions. In South Asia and sub-Saharan Africa, more than half of waste material is openly dumped, whereas in North America almost no waste is openly dumped (Kaza et al., 2018). However, **trends reveal that countries are shifting toward sustainable waste infrastructure.** Countries with the least material management capacities are incorporating more sanitary landfills and recycling facilities; countries that already have a robust material management system are transitioning to more resource-recovery pathways.

Increase of landfill usage in North Africa

Morocco is improving its MSW collection rates and is disposing of more material in sanitary landfills. Sanitary landfill disposal has increased from 10 per cent in 2008 to 32 per cent in 2012 and to 53 per cent in 2016 (Kaza et al., 2018). The latest figures show that 37 per cent of MSW was placed in landfills and 8 per cent of MSW was recycled in 2013 (D-Waste, 2014). Numbers for controlled and sanitary landfills increased to 15 in 2013, up from six in 2008, 10 in 2010 and 13 in 2011 (D-Waste, 2014). Efforts are now focused on proper handling of industrial and medical waste material.

MARKET

Grey material management systems are facing a shift in the market toward greener management systems. The past years have **seen relevant commodity shifts,** especially since China's National Sword policy that banned post-consumer plastics and mixed paper (Read & Vinogradova, 2018). Many countries rely on waste material exports as part of their recycling strategies because they do not have enough capacity to do so (Hook & Reed, 2018). More sustainable infrastructure capacity needs to be built so that countries are able to process their waste materials independently.

Effects of China's National Sword policy

The National Sword policy sent shockwaves throughout the recycling world (Hook & Reed, 2018). Malaysia, which became the biggest importer of plastic scrap in the aftermath, is following suit in limiting waste imports from other countries (Hook & Reed, 2018). Thus, the sorting and recycling capacity of Europe, which is the major source of material exports (1,154,000 tonnes for Germany, United Kingdom, France and Italy alone), will have to increase (Hook & Reed, 2018). The long-term impact will see a push for global improvement in material quality since most plants are not able to process the plastic and paper waste that they usually export (Read & Vinogradova, 2018).

TECHNICAL

Grey infrastructure does not keep the waste hierarchy in mind, and thus, cannot fulfill efficient and sustainable material management systems that respect environmental, economic and social aspects. In addition, material management systems are increasingly complicated. The ISWM system encourages sustainable material management strategies and incorporates stakeholder input.

Financing unsustainable waste infrastructure in the United States

In the United States, bills have been passed in 31 states that designate MSW as a renewable source of energy; WtE is active in 23 states (Ecocycle, 2011). However, these incineration facilities act as incinerators under loosely defined boundaries of sustainable versus unsustainable waste management. Facilities receive subsidies and loans. These cost-inefficient facilities cannot be downscaled, as large loans are attached to them, crowding out other material management systems. However, the Energy Policy Act of 1992 focused on increasing energy security and economic efficiency, which decreases environmental harm and presents a possibility for Congress to exclude WtE from future funding, rendering WtE unprofitable in the future (McAnulty, 2019).

SOCIAL PRESSURE

The public has responded negatively to poor material management because of the externalities they have to face, like health effects, economic loss and disamenities. Community-based movements have surfaced to oppose the construction of landfill sites or to call for better waste material management standards (Ferreira & Gallagher, 2010).

Opposition of landfill siting in Hong Kong

The Legislative Council has planned to expand the Tseung Kwan O landfill in Lohas Park, Hong Kong. Residents organized to voice their opposition to the siting, citing reasons like garbage stench and GHG emissions. Other landfills are expected to be at capacity by 2019, and there are no plans to introduce incineration. The protests generated enough pressure for the government to make a decision that the landfill will receive C&D material only. Furthermore, a study in Ireland showed strong opposition to new incineration and landfill infrastructures, even after incorporating payment mechanisms

3.2 Green Infrastructure

3.2.1 Regulatory

The **policy and regulation environments for green infrastructure are changing** and can create uncertainties for infrastructure implementation (Winne et al., 2012). In the previous section, we raised the example of China's National Sword policy and how it changed the playing field for recyclables and countries' capacity. However, some countries **do not have the proper regulatory framework and standardized** waste management systems to implement sustainable infrastructure effectively (Kaza et al., 2018). Furthermore, even if countries have the capacity to practice sustainable material management and effectively deploy sustainable material management infrastructure, they may be **subjected to other environmental, health and social regulations that are changing.** In the WtE industry, modern incineration has come a long way in developing environmentally and socially sound practices, forged by strong public opposition and improved regulation (Brunner & Rechberger, 2015). Renewables obligations, portfolio standards and FIT incentives may provide investor confidence to invest in the development of EfW, but **fluxes based on political economy will decrease confidence (APSRG, 2012).**

LACK OF STANDARDIZED REGULATIONS IN INDIA

India has huge potential for sustainable MSW management. The benefits brought by sustainable waste infrastructure and management include increased recycling, land restoration, job creation and energy recovery (Srivastava et al., 2015). However, the lack of standardized regulations is a challenge to implementing sustainable material management infrastructure in India. India has only central legislation on handling waste material called the MSW (Management and Handling) Rules. However, it does not contain specific regulations for different waste or material types (Waste Management Review, 2016). The rulemaking power for developing infrastructure and separating material streams falls to municipal authorities. Yet there is a lack of coordination between central and state governments (Joshi & Ahmed, 2016). The main barriers faced by local authorities are having a regulatory framework to implement strategic MSW plans and providing a steady stream of financing to support effective infrastructure.

3.2.2 Market

Market conditions surrounding sustainable infrastructure are especially volatile. These market barriers include the **infeasibility of small-scale operations,** the **risk of merchant facilities** and **volatile prices for commodities.** Consumer waste has the highest extractable value in aggregate (Engel et al., 2016). Hence, the challenge to achieving a feasible and profitable operation is in increasing infrastructure capacity to yield "high-performing value recovery" or risk making a loss. The fluctuation of commodity prices and its impacts will be addressed in an example below.

The decentralization of material management also acts as a risk to potential investors. In the United Kingdom, many local governments have contracts with independent merchant facilities to construct and operate sustainable material management infrastructure, but on a small scale. Investors may view small projects as risky and financially unsustainable (APSRG, 2012). Thus, merchants and local authorities may experience more variable market pricing and greater market risk (Green Investment Bank [GIB], 2014). Additionally, C&D and household waste material generation are difficult to forecast due to their reliance on recession and other consumption trends.

Concerns over WtE leading to **the crowding out of recycling** have been raised over the years (Euractiv, 2013; Luthra, 2017; OECD Competition Committee, 2013). A study in India shows that the emergence of WtE deployment has led to competition over high-calorific material, especially in the informal recycling industry, which accounts for 10 per cent of waste material management (Luthra, 2017).

VOLATILE COMMODITY PRICES

Mixed paper market prices started to fall when China phased out purchasing secondary paper (Recycling Today, 2018). Mixed paper prices dropped further by 60 per cent after the implementation of China's National Sword policy (Read & Vinogradova, 2018). This has redirected waste material to Southeast Asia and mixed paper accumulation in countries that usually export. Under limited storage capacity, European countries may turn to incineration or landfills as a solution to process these wastes.

3.2.3 Technical

There are a number of barriers to sustainable material management infrastructure. The first aspect to consider is the **economic cost of the different processes available to recover, process or reuse material.** Different sites have different technical risks, and therefore cost, attached to the facilities. For example, in landfill sites, there are long-term risks of pollution and contamination through leachates (Hopewell et al., 2009). Service providers and investors may be liable for these risks contingent on contractual agreements and legislative contexts. At the same time, these liabilities are in place for environmental protection (Luppi et al., 2012).

PLASTIC CONTAMINATION

Plastic contamination is a problem for recycling streams because it decreases the economic value of the plastics and reduces its ability to be reused. PVC contamination is common in the PET recycling stream. PVC degrades recycled PET resin because of hydrochloric acid gas released in the processing stage (Hopewell et al., 2009). In 2017, the average price for recyclables in the United States was USD 115/tonne of clean material, whereas contaminated recyclables were priced at only USD 77/tonne (World Bank Group, 2018).

3.2.4 Social Pressure

The **general public may view material management infrastructure as negative,** and thus may not understand the difference between grey and green material management infrastructure. Therefore, there is a risk in implementing sustainable material management infrastructure, especially in local municipalities. The ISWM system incorporates the engagement of multiple stakeholders and may pose the additional risk of failing to receive approval for projects, regardless of their sustainability. The approval process may be long and arduous, depending on the existing regulations and how receptive the community is to the new infrastructure.

SOCIAL ACCEPTANCE OF WTE PLANTS IN THESSALONIKI, GREECE.

Social pressure is an important decision factor in implementing ISWM systems in Greece. Previous literature has demonstrated that NIMBY-ism manifested because of a lack of understanding of waste management operations, as well as the difference between grey and green infrastructure. The study demonstrated that individuals who had more knowledge of recent abatement technologies and waste management were less opposed to incineration. However, this is also guided by the population's trust in the public authority to regulate these facilities (Achillas et al., 2011).

4.0 Obstacles and Opportunities

4.1 Obstacles

Waste generation rates are increasing and so is the complexity of waste types. Across the world, waste generation per capita increases as GDP increases, driven by increased purchasing power in many emerging economies (UNEP, 2011). Waste material streams become more complicated and varied as countries become richer as well: low- and middle-income countries generate more organic material, and high-income countries produce more paper and plastic material (UNEP, 2011). Thus, as the world population increases, material management systems will need to adapt to changing waste material composition and volume by building sustainable systems that respect the waste material management hierarchy. Strong citizen perspectives against waste infrastructure, as discussed above, also present barriers to the implementation of sustainable material management infrastructure (Monier et al., 2017).

A huge challenge in approaching sustainable material management infrastructure is **in identifying and projecting the waste material management capacity** that a locality requires. Sustainable material management infrastructure will only be effective with the support of data and standardized indicators to: 1) understand the current waste material generation rates and composition, 2) project the needs of the specific municipality, 3) propose solutions that cater to the need of the region, and 4) to monitor its effectiveness and sustainability (UNEP, 2011). The waste material industry represents a growing source of GHG emissions. Thus, national data on waste material industry emissions will be helpful in determining the appropriate strategies to reduce and capture end-of-life gases like methane and fluorinated gases (Bogner et al., 2007).

DATA-DRIVEN EFFICIENCY IN MSW MANAGEMENT IN JAPAN

Japan has a high waste material diversion rate, with only 1 per cent of their annual waste materials ending up in landfills. The Ministry of Environment manages a transparent data system so that they are able to monitor different material management plans, strategies and policies that have been implemented. The database allows better development of MSW plans, construction of appropriate waste material infrastructure and exchange of best practices on a national level. The 2016 survey covered 1,714 municipalities and 578 special district authorities (Kaza et al., 2018).

Infrastructure projects can be difficult to implement because they **involve many stakeholders and require coordination** across governments, landowners, residents and more (Ehlers, 2014). Infrastructure is successful only when it meets the needs of the community it serves.

THE IMPORTANCE OF STAKEHOLDER INPUT IN SOLID WASTE MANAGEMENT SYSTEMS IN BUSIA, UGANDA

Stakeholders in Busia, Uganda, were interviewed to identify the gaps between the government's perceived needs of material management and the actual demands of the population. A previous attempt to introduce plastic recycling infrastructure in 2007 was unsuccessful because of disagreements between the public and non-governmental groups. In a separate case, a CDM composting project was implemented in 2012, but the local community did not feel involved in the program design. The study revealed that the local community had rich information and insights about organic material management that were not expressed in the CDM program implementation. The lack of revenues and high operating costs of the CDM program in 12 other towns led to a delay in the construction of the composting infrastructure in Busia (Lederer et al., 2015).

Different maturity levels of waste material management legal framework across countries mean that the feasibility of sustainable infrastructure types will differ (Monier et al., 2017). Many developing countries do not have appropriate definitions or legislation to deal with waste material, particularly hazardous and health-sector materials (Modak et al., 2015).

C&D WASTE RECOVERY AND LEGISLATIVE MATURITY ACROSS THE EU

In the EU, member states have varied legislative structures and national plans on C&D waste management. The report singles out Germany, France, the Netherlands and Belgium as most advanced in waste management regulations. The EU has established a target to recover 70 per cent of waste by 2020, which may be achieved through increased gate fees and landfill taxes. Barriers to achieving the target are proper enforcement of laws and infrastructure for recycling and recovery. The efficiency and effectiveness of material management infrastructure are also affected (Monier et al., 2017).

The waste management industry has a huge financing gap. Infrastructure, including technological, transportation, storage, processing and operation aspects, are costly (Kaza et al., 2018). The waste material infrastructure gap stands at 1.39 billion tonnes of MSW of capacity by 2050 (Kaza et al., 2018). The financing gap for waste and water (2015–2030) currently stands at USD 19 trillion, which represents 21 per cent of the total infrastructure demand (Bielenberg et al., 2016). Many municipalities require funding in order to move forward with sustainable material management systems, as material management is a significant expense in municipal budgets. On average, the percentage of municipal expenditures on SWM for high-, middle- and low-income municipalities are 4 per cent, 11 per cent and 19 per cent, respectively (Kaza et al., 2018).

FUNDING WASTE MANAGEMENT INFRASTRUCTURE IN SOUTH AFRICA

The South African government realized that waste material management was a growing issue for the country. South Africa started off with increased landfilling from the late 1980s, before the emergence of the recycling economy in 2001. Material management became more stringent with the introduction of additional regulation, as well as the introduction of EPR. Throughout these different stages, funding was a key driver of these transitions. The Danish Cooperation for Environment and Development provides large funding and technical support to develop landfill infrastructure in South Africa. Under the EPR movement, the main obstacle in advancing the effectiveness of the scheme is raising sufficient funding for material management infrastructure and services like collection and sorting. Benefits have resulted from the financing and restructuring of material management systems. Employment has increased from 9,107 in 1997 to 27,347 in 2007 (Godfrey & Oelofse, 2017; Madubula & Makinta, 2014).

The lack of a technology track record for feasibility of sustainable material management infrastructure and technology may deter new investors (NERA, 2015).

PERCEPTIONS OF GREEN INFRASTRUCTURE RISK IN THE U.K. (NERA, 2015).

The U.K. GIB, now known as the Green Investment Group, conducted a survey of market participants on their green investment impacts. Results showed that technology risk ranked as the highest barrier to investment in material management and bioenergy infrastructure. Therefore, GIB has chosen to finance immature technologies to develop these technologies and lower associated risks. Financing from the GIB has been deemed "relatively successful" in addressing technology risk barriers.

4.2 Opportunities

The challenge of **increased waste generation** is, at the same time, an opportunity for the implementation of sustainable material management infrastructure. Waste material generated by cities is expected to increase to 3.40 billion tonnes annually by 2050, and so cities need to increase their waste-processing capacity (Kaza et al., 2018).

ZERO WASTE EUROPE

The Zero Waste Europe movement is a network of European NGOs committed to reducing waste material generation and improving waste material sorting in cities. Member NGOs and their municipalities agree to prioritize the zero-waste hierarchy, as well as the network's main principles, which include a push for infrastructure adaptation. Currently, 31 national NGOs help to monitor and promote end-use material reduction practices, connecting companies, decision-makers and civic society (Zero Waste Europe, n.d.).

Sustainable material management has recently been recognized as **a solution for climate mitigation.** The C40 Cities group, a network of megacities that are working together to address climate change, launched a Sustainable Waste Systems Network to reduce carbon emissions by improving on material management systems in cities (C40 Cities, 2016). These cities recognize that waste material management is expensive. In lower-income countries, municipalities may spend up to 50 per cent of their budget on solid waste management (Mugabi, 2014). Thus, introducing appropriate material infrastructure can help reduce these costs in the long run. The example below talks about mechanisms that have been in place to incentivize carbon reduction via sustainable material management infrastructure.

CARBON MITIGATION VIA LANDFILL GAS RECOVERY PROJECTS

Through the CDM, many landfill gas recovery projects have been developed to reduce carbon emissions. As of 2006 (CDM projects ended in 2018), there were 33 landfill gas projects that represented 12 per cent of the registered carbon emissions reductions (CDR) credits. These projects have created an opportunity to build and redesign material management systems, so that negative externalities like GHG emissions can be avoided (Markgraf & Kaza, 2017).

The average global recycling rate is about 13.5 per cent, which decreases across income levels (Kaza et al., 2018). There has been an **increase in plastics recycling over the years.**

Plastics recycling only started to take place in the 1980s, with global annual recycling rates increasing from 0.7 per cent to 20 per cent in 2015. The private sector has been more involved in the solid material management industry by providing management services, infrastructure and operation support (EMF, 2013). The EMF (2013) projects that the circular economy is a billion-dollar investment opportunity: sustainable material management infrastructure yields net material cost savings of USD 340 bilion–630 billion per year in the EU.

MAKING THE BUSINESS CASE IN THE MALDIVES

Since the 1980s, the International Finance Corporation (IFC) established a track record of private sector participation in the waste material management sector. In the Maldives, the IFC is financing an ISWM project for four Maldivian islands that generate an average of 400 tonnes of waste daily. The collection has been inefficient and unsustainable. Thus, the government is interested in partnering with local governments to introduce more efficient material collection, sorting and processing services. The IFC invested USD 50 million into building a mechanical biological treatment centre for material sorting and a 2.7 MW WtE gasification facility (Michelsen, 2012).

The GPP space is increasingly popular for governments and the private sector as well. Since governments in Europe spend 14 per cent of the EU GDP (EUR 1.8 trillion) in the procurement space annually, the EC has since recognized the importance of advancing sustainability goals in line with expenditure (DG GROW-G4, 2015). GPP has taken off globally, with successful case studies from Thailand to Denmark to Peru (Benavides et al., 2016; EC, 2017; Green Purchasing Network Malaysia, 2017). The EC has defined circular procurements as "the purchase of works, goods or services that seek to contribute to the closed energy and material loops within supply chains, while minimizing, and in the best case avoiding, negative environmental impacts and waste creation across the whole life-cycle" (ICLEI, 2016).

EU GPP TRAINING TOOLKIT IN CIRCULAR ECONOMY

The EC has released a series of information tools promoting GPP for public purchasers. These entail detailed modules on how to engage, assess and implement GPP. Modules focus heavily on circular economy designs and how to transition within various industries like computers and monitors, road transport, and office design and construction. Under the EU Action Plan for the Circular Economy, the EU saw EUR 17.5 billion in investments in circular activities and EUR 147 billion of value added within the system in 2016 alone (EC, 2019a, 2019d).

Furthermore, recent **export bans and tighter waste import policies** call for more local solutions (Hook & Reed, 2018). Between 2010 and 2016, China imported 7 million to 9 million tonnes of plastic waste annually (Ritchie & Roser, 2018). A study estimated that the ban would displace 110 million tonnes of plastics by 2030 (Brooks et al., 2018). The best solution is to increase recycling infrastructure domestically and to create internal markets for processing waste (Brooks et al., 2018). Currently, the mismanagement of plastic waste is apparent in middle-income countries that are rapidly industrializing (Ritchie & Roser, 2018). Therefore, material management systems need to adapt and catch up with waste generation rates in these countries.

4.3 Policy Interventions

Sustainable material management infrastructure is mainly enabled by targets, market instruments and incentives. Existing legislative mechanisms complement these targets and market instruments. Market instruments and incentives have the potential to generate market forces and opportunities to transition from grey to green infrastructure. There is increased momentum for information-based instruments, especially with labelling and certification. NGO and voluntary networks also have a strong presence in the green material management sector and provide monitoring and naming/shaming mechanisms in the system. Furthermore, policies that support infrastructure financing are increasingly important in bridging the material management gap.

The increase of waste generation has led to the development of new regulations to manage waste material under the waste hierarchy, which prioritizes end-use material prevention and reduction. The types of waste material regulations vary from country to country, primarily due to the maturity of existing legislation and the rate of end-use material generation. Countries with an established material management track record are now moving toward policies that focus on implementing the material management hierarchy. Other countries that have not established a proper waste framework are working toward creating one. Primary factors affecting the solid material management landscape are informal recycling and reuse, public health, local environmental concerns, resource scarcity and climate change (Wilson & Rogero, 2015). This review will explore the different policy interventions that have the potential to help implement a sustainable material management system. The policy and regulation lenses used here are outlined in Taylor et al. (2012).

4.3.1 Legislative Mechanisms

Legislative mechanisms are crucial for establishing a framework to guide and coordinate material management systems across governments and stakeholders. Solid waste material management is usually regulated and funded by local governments. However, national-level legislation often defines the boundaries of material management and allocates executive authority to local governments to meet material management needs. This includes outlining compliance procedures, standards, penalties and monitoring mechanisms (Rodic, 2015). In *What a Waste 2.0*, the World Bank reports that approximately 86 per cent of the 217 countries in their study has an official national law or guideline on solid material management (Kaza et al., 2018). Only 60 per cent of low-income countries have defined laws or guidelines.

Table 2 and Section 4.2.2 give an overview of the general legislative mechanisms to establish material management systems within the international community. The approach to material management originates from the perspectives of waste material prevention, environmental protection, public health, energy conservation and resource recovery. Legislative frameworks help shape the landscape of regulations, policies and initiatives that lead to specific regulatory mechanisms. The PPP underlies many examples of material management legislation that allocate liability to polluters. PPP helps prevent pollution because polluters are subjected to bearing the costs of damage from the pollution they produce. The Danish waste material management system, designed under the Danish Environment Protection Law of 1982, is an example of a well-designed material management plan with specific waste material targets (Danish EPA, 2013). Table 2 outlines some of the mechanisms that contribute to the success of sustainable waste infrastructure implementation.

However, this is not the case for international law. Materials are increasingly global commodities, being traded between countries without sharing proper definitions of waste material types and discretion on processing pathways (Barsalou & Picard, 2018). International law approaches to material management have overgeneralized waste material so that regulations are limited to explicitly defined waste materials rather than tackling the nature of material generation (Barsalou & Picard, 2018). Currently, international legislation on material management is focused on transboundary transportation and disposal of hazardous waste or goods.

Table 2. Different legislative approaches to installing material management systems

Type of Legislation/ Agreement	International	Domestic
Waste material prevention	**Basel Convention (1989)** The Basel Convention is an international treaty that regulates the movement of hazardous waste, particularly from developed to developing nations. The globalization of waste trade led to the mismanagement of hazardous waste internationally.	**Environmental Protection Act, UK (1990)** The UK passed the Environmental Protection Act in 1990, which outlines the waste management system to deal with problems of waste control on land. The act was later amended to control emissions. The act also sets the basis to implement the EU Waste Framework Directive in the region.
Public health	**Minamata Convention (UN Environment, 2017)** The Minamata Convention on Mercury protects public health and the environment from goods and services that release mercury and mercury compounds. Although the convention focuses on mercury alone, these concern the disposal of solid products that store or contain mercury, like batteries and compact fluorescent lamps. *See also: Rotterdam Stockholm Convention*	**Health Services Act (2002), Health Services (Nuisances) Regulation (1969), Health Services (Disposal of Offensive Matter) Regulation (1969), Barbados** Barbados does not have solid waste management legislation; rather, waste management is governed by three separate pieces of legislation. These regulations are the Health Services Act of 1969 (promotion and preservation of health), the Health Services (Nuisances) Regulations of 1969 (prohibiting nuisances of solid waste) and Health Services (Disposal of Offensive Matter) Regulations of 1969 (restricting disposal).
Environmental protection		**EPA Switzerland (1983)** Switzerland's material management relies on the PPP, which holds the polluter accountable for the cost of their actions. Under the EPA, the prevention, collection, treatment, recovery and disposal of waste are outlined.

Type of Legislation/ Agreement	International	Domestic
Pollution	**International Convention for the Prevention of Pollution from Ships (MARPOL) (1973)** MARPOL is an international convention that prevents marine pollution caused by accidents due to the operation of ships. Annex V entered into force on December 31, 1988, containing language on the "prevention of pollution by garbage from ships." The convention lists types of banned garbage, which includes plastics.	**Waste Management and Pollution Control Act, Australia (1998)** The act outlines the administrative authority and their environmental duties in detail, including the issuance of approvals and licences for waste disposal. Additionally, the act includes environmental audit processes, compliance planning guidelines, penalties and liabilities to provide an enforcement mechanism.
Energy		**Maryland Clean Energy Jobs Act (2019), Washington, D.C. Clean Energy Act (2018), USA** Clean Energy Jobs Act of 2019 and Clean Energy Act were passed in Maryland and Washington, D.C., respectively. The bills recognize WtE measures as renewable energy sources, which boosts the market for this infrastructure
Resource recovery	**OECD Control of Transboundary Movements of Wastes Destined for Recovery Operations (OECD, 1992)** The OECD Council signed into action the Control System to further regulate recyclable wastes. The council noted that the recovery of valuable materials and WtE are valuable in the economic system but require environmental and economic considerations.	**Food Waste Recycling Law, Japan (2001)** Prior to the introduction of the law, 30 per cent of MSW volume was food waste. The law now delegates responsibility to business entities to increase food waste recycling. Recycling rates increased to 50 per cent in 2004 from less than 10 per cent in 2002 (Japan for Sustainability, 2006).

4.3.2 Existing Framework

Table 3. An overview of legislation and management of different materials across regions

Electronic waste	
Asia	Only five out of 11 East and Southeast Asian countries have e-waste-specific legislation (Honda et al., 2016). There is an overall lack of coordination between government departments. Countries in this region experience large influxes of e-waste from developed nations.
Europe	Countries in the EU adopted the Waste Electrical and Electronic Equipment (WEEE) Directive (2003). The EU has banned exports of hazardous e-waste to developing countries (Modak et al., 2015).
North America	The Commission for Environmental Cooperation (CEC), established under the North American Agreement on Environmental Cooperation, has released a project for sound management of electronic wastes (CEC, 2011).
Latin America and the Caribbean	Most Latin American countries have ratified the Basel Convention. Only some countries have specific e-waste legislation. E-waste generally is regulated under hazardous waste legislation (Magalini, Kuehhr, & Baldé, 2015). E-waste regulations are only present in seven countries in the region (Böni, n.d.).
Africa	Local e-waste generation makes up 50–85 per cent of total e-waste. The remaining percentage is imported illegally from mostly developed countries (Baldé et al., 2017). Only Madagascar, Kenya and Ghana have e-waste laws. Four other countries are in the process of electing similar regulations. However, South Africa has successfully introduced legislation to extend EPR to WEEE products (Forti et al., 2018).
Oceania	Only Australia has implemented a law on e-waste management in the region (the Product Stewardship Act 2011). New Zealand is developing a national e-waste regulation (Baldé et al., 2017). The Pacific Islands are facing unique challenges in waste material processing and collection due to geographical challenges.

Hazardous waste	
Asia	China has a hazardous waste management structure, with identification, incineration and landfill standards (Asia Hazardous Waste Treatment Congress 2017). Most of Southeast Asia's laws on hazardous waste are outdated, but some do specify standards on handling, treating and disposing of hazardous material (Jain, 2017).
Europe	The UK's 2005 Hazardous Waste Regulations provide the framework for hazardous material management (Gov.uk, n.d.). The EU Commission classifies hazardous versus non-hazardous waste. However, 10 out of 14 member states do not have proper hazardous material treatment infrastructure (EC, 2019c; Hazardous Waste Europe, 2017).
North America	The United States, Mexico and Canada have their respective legislations on hazardous waste treatments (i.e., the RCRA, the Canadian Environmental Protection Act and the General Law of Ecological Equilibrium). The North American Free Trade Agreement also regulates hazardous material management (Reed et al., 2000).
Latin America and the Caribbean	A few countries have implemented hazardous waste management, including Costa Rica, Colombia and Mexico. The Basel Convention has built capacity in Latin America through its Basel Convention Regional Centres for Training and Technology Transfer (BCRC) in Argentina, El Salvador, Trinidad and Tobago, and Uruguay (PTB, n.d.)
Africa	African Nations established the Bamako Convention in 1991, complementing the Basel Convention in preventing the import and dumping of hazardous material (UNEP, 2018b). Most hazardous waste in Africa is in the form of e-waste, both imported and generated locally (Eneh & Agunwamba, 2011).
Oceania	Hazardous material management frameworks are well established in Australia and New Zealand. In the Pacific Islands, hazardous waste comprises healthcare, e-waste, asbestos and ISWM. Pacific Hazardous Waste (PacWaste) is currently implemented by the Secretariat of the Pacific Regional Environment Programme (SPREP) (PacWaste, n.d.).

Plastics and packaging	
Asia	Regulations on plastic material in Asia, particularly Southeast Asia, developed because of the influx of plastic material imports from developed countries after China's plastic import ban (Lee, 2019). The Asian Plastics and Packaging Agreement was established to support the industry in cutting down on packaging (Circular Economy Asia, n.d.)
Europe	In 2018, Europe adopted the European Strategy for Plastics in the Circular Economy to reduce and transform plastic products (EC, 2018). 173 waste prevention measures are identified. However, only nine countries have plastic waste prevention targets in place (EEA, 2019).
North America	The United States exports 70 per cent of plastic waste. It also failed to sign an amendment to the Basel Convention to restrict shipments of plastic waste materials (Holden et al., 2019). The Canadian government is working toward reducing plastic pollution, launching a private industry-linked zero plastic waste goal and a recent ban of single-use plastics (Environmental Defence, n.d.; Prime Minister of Canada, 2019).
Latin America and the Caribbean	Many Latin American countries are on board with UN Environment's Clean Seas campaign that aims to reduce consumption of single-use plastics and microbeads (UNEP, 2018c). Chile, Costa Rica, cities like Rio de Janeiro and states like Baja California have enacted bans and taxes on single-use plastics (i.e., bags and straws) (The National Law Review, 2018).
Africa	In Africa, 34 countries have implemented bans against single-use plastics, leading the world's movement against plastics (Livni, 2019). Monitoring and enforcing these bans is difficult. However, plastic bag bans may be effective in reducing toxic fumes from poor material management (UNEP, 2019).
Oceania	New Zealand and Australia do not have legislation on plastic and packaging, but they do have voluntary agreements between industry and the government. Both countries have legislation to phase out microbeads (Department of Environment and Energy, 2018; Plastics NZ, 2019). Plastic material management for the Pacific Islands is challenging because infrastructure capacity is low. However, the Secretariat of the Pacific Regional Environment Programme (SPREP) focuses on plastic waste management (SPREP, 2018).

Healthcare waste	
Asia	Asia, Japan and Singapore have good healthcare waste management systems because of financial and policy support. Malaysia, the Philippines and Vietnam are World Health Organization (WHO-) compliant. However, other countries have different statuses across segregation to disposal stages (Prem et al., 2010). Countries like Sri Lanka and India are starting to practice basic segregation nation-wide (WHO, 2017).
Europe	The EC sets standards for medical waste, governed under the category of hazardous waste (Bakiu & Durmishaj, 2018). Europe is moving away from incineration of medical waste materials, using technology like autoclaves instead. National definitions and classifications are still prioritized within the European Union.
North America	There are many companies that specialize in processing biomedical waste in the United States. (Rinkesh, n.d.). U.S. states have the authority to regulate the disposal method (U.S. EPA, n.d.a). In Canada, healthcare materials are increasingly processed by third parties. Provinces have the authority to enforce standards (Walkinshaw, 2011).
Latin America and the Caribbean	In the Caribbean, there is no medical waste material legislation. However, St. Lucia and Jamaica have implemented facilities and are building capacity to properly treat medical waste (Riquelme et al., 2016). Latin American countries are preparing legal frameworks to regulate healthcare waste, but infrastructure capacity (i.e., incineration, microwaves, autoclaves, sanitary landfills) is lacking (Savino et al., 2018).

Africa	South Africa has the best practice for solid medical waste in the region, according to WHO guidelines (Udofia et al., 2015). 18 out of 20 African countries reported that medical waste undergoes advanced thermal treatment, meeting the WHO compliance standards (WHO, 2017).
Oceania	The Pacific Islands practice healthcare waste material management, but there is a lack of documentation and planning in 84 per cent of sampled hospitals, with poor segregation and inadequate facilities (SPREP, 2016). There are no healthcare waste laws in Australia and New Zealand, but there are policy frameworks and guidelines for handling healthcare waste material (WHO, 2015).
Food and other organics	
Asia	Asia is the global leader in generating vegetables, cereals, starchy roots and fruits waste, contributing to over 50 per cent of global food wastage (Pariatamby, 2017). On the other hand, Japan is a leader in food waste minimization, with legislation targeting food waste recycling and treatment.
Europe	Many European countries have food waste prevention or recycling strategies at the national level (Koester et al., 2013). The EC launched the EU Action Plan for the Circular Economy with revised EU waste legislation in 2018, aiming to combat food waste throughout the supply chain (EC, n.d.) Most food waste comes from agricultural production caused by poor storage facilities or outdated technologies (Koester et al., 2013).
North America	In 2013, 38.6 billion m^3 of food waste ended up in landfills (CEC, 2017a). The region participates in the North American Climate, Clean Energy, and Environment Partnership Action Plan, as well as the North American Initiative on Food Loss and Waste Reduction and Recovery (CEC, 2017a). Each country has a strategy and targets to minimize food material waste (CEC, 2017a).
Latin America and the Caribbean	Latin American and Caribbean countries have committed to halving per capita food waste and losses by 2025 (Food and Agriculture Organization of the United Nations [FAO], 2016). The region has advanced effectively in the prevention and reduction of food losses and waste. Currently, 33 countries in the region have highlighted food loss and waste prevention (FAO, 2016).
Africa	African countries are not on track to meet their targets of reducing post-harvest loss by 2025 (Farming First, 2019). Furthermore, the food market infrastructure, like road networks and electricity access, may contribute to post-harvest loss reduction (Sheahan & Barrett, 2017). South Africa is taking initiatives to compile data and release policy suites under supporting legislative framework to reduce food waste (WWF, 2017).
Oceania	In Australia, the National Food Waste Strategy was launched in 2017 to reduce food waste by 50 per cent by 2030 (Too Good To Go, n.d.). There is no federal strategy in New Zealand to tackle food waste, but councils and municipalities are part of a movement to reduce wastage (Love Food Hate Waste, 2019). Organic material streams in the Cook Islands, Kiribati, Nauru, Nieu, the Solomon Islands and Tonga are addressed in their respective national waste strategies (Guinto & Makoto, 2017).
Biomass and agricultural waste	
Asia	Many Asian countries generate a large amount of agricultural waste, which excludes livestock waste (Modak et al., 2017). Agricultural materials have been dealt with via food waste policies and biomass treatments (Modak et al., 2017). Biomass treatments, which include bioenergy and composting, have been deployed in Japan, Indonesia, Malaysia, Thailand, Vietnam and China (Modak et al., 2017).
Europe	The EC has mentioned agricultural plastics as an official waste type and requires the introduction of EPR in member states (AEBIOM, 2018, p. 3). Agricultural waste has also been addressed in the context of food waste in Europe. Agriculture residues may be used to generate biofuels. However, the EC has excluded agricultural residues as waste in the Waste Framework Directive (EU Waste Framework Directive, 2008).

North America	In the United States, rules and legislation affecting agricultural materials touch upon environmental pollution from fertilizers and agricultural discharge (National Association of State Departments of Agriculture, National Center for Agricultural Law Research and Information, Natural Resources Conservation Service, & U.S. Environmental Protection Agency n.d.) Other regulations concern livestock waste pollution. Canada has been encouraging co-digestion of agricultural residue and manure to generate energy (CEC, 2017b).
Latin America and the Caribbean	Agriculture waste regulations in Latin America mainly concern food waste prevention (FAO, 2016). However, the market for bioenergy and fuels is booming. Different countries currently have tariffs and incentives in place to utilize biomass and agricultural residue to generate energy (Kieffer et al., 2016).
Africa	African countries do not have waste management regulations for biomass and agriculture, even though this primary industry is a big part of the economy. To deal with agricultural residue, WtE processes have been increasingly popular. Morocco practices resource-efficient measures and reusing agricultural residues for energy, while other countries have had opportunities to develop projects under the CDM (Committee on Food Security and Sustainable Development, 2009; UN Economic Commission for Africa, n.d.).
Oceania	Australia has legislation on biowaste transportation to prevent the introduction of exotic pests and diseases (Australian Department of Agriculture, 2016). Another form of agricultural residue regulation is the limitation of open burnings. New Zealand has strict limits on agriculture burning, whereas Australia has a permit-based system that may allow more burning to occur (Federated Farmers & Fire Emergency NZ, n.d.; NSW Australia EPA, n.d., p. 4).

Metal (non-hazardous)	
Asia	The metal collection and recycling industry in Asia is largely unregulated. There are no metal-waste-specific regulations. However, in industries like the ELVs and ship-breaking, nations have conventions or agreements to prevent and reduce harm to the environment and human health (Modak et al., 2017). Japan has recycling laws for construction material and ELVs that include metal regulations.
Europe	Under the Waste Framework Directive, the EC has included end-of-waste criteria for three main waste streams: glass cullet; copper scrap; and iron, steel and aluminum scrap. Furthermore, heavy metals are also addressed under the WEEE Directive (see above). Many European countries have also ratified the Hong Kong Convention on ship recycling to address the environmental and social impacts of scrap recovery (International Maritime Organization, n.d.).
North America	The United States has regulations for metal scrap and end-treatments under the North American Free Trade Agreement Implementation Act (U.S. Customs and Border Protection, 2010). The act allows imported scrap to be treated in the United States, including recycling processes. The United States also regulates heavy metals under the Hazardous Waste Program, as part of RCRA (U.S. EPA, n.d.b).
Latin America and the Caribbean	Non-hazardous metal waste is not well-regulated in this region. Hazardous metals are mainly regulated under e-waste frameworks, which are already sparse (see above).
Africa	African countries participate in scrap metal imports (Muchová & Eder, 2010). However, there are few regulations surrounding metal scrap processing and recycling. In many countries, metals are addressed under e-waste regulations. The South African Waste Act and Swaziland (Eswatini) Waste Regulations refers to metal waste management (National Environmental Management: Waste Act, 2008 [Republic of South Africa, 2009]; EU Directive 2000/53/CE, 2000).
Oceania	In the Cook Islands, New Zealand has stepped in to co-fund the removal of metals in the area (Pacific Regional Solid Waste Management, 2010). Most of the metal in the Pacific Islands are recovered and exported to other countries, including Australia and New Zealand (SPREP, 2016). In Australia and New Zealand, private companies participate in importing and recycling metal waste. The Australian government requires operators to hold licences to treat metal (South Australia EPA, 2019).

Table 4. Policy approaches to sustainable material management

Policy	Definition
Command-and-Control Approaches	
Waste directives	Waste directives can tackle a particular stage of the waste management process, like the prevention of waste generation and the act of disposal, or a broader management scheme or strategy, like the EU Waste Directive (2008). *Example: The RCRA of 1976 was passed in the U.S. Congress to regulate hazardous waste materials from "cradle-to-grave" (RCRA, 1976). The regulation entailed specific steps in waste management for waste with different degrees of risk.* *See also the WEEE Directive from the European Commission (2003).*
Waste targets	Waste targets are usually measurable objectives of waste reduction, minimization, diversion, reuse or recycling. *Example: The city of San Francisco announced a zero-waste target by 2020 and has passed a series of material bans since 2006, including Styrofoam and plastic bags (Kaza et al., 2018).* *Example: The EU has passed several directives restricting hazardous waste content in products, like the European 2006 Directive on batteries that prohibits more than 0.0005 per cent mercury and 0.02 per cent cadmium content by weight (Directive 2006/66/EC, 2006).*
Portfolio standards and FITs	Portfolio requirements or standards blend command-and-control mandates and free-market approaches to managing the environment. Although no portfolio requirements are specified for waste infrastructure in general, renewable portfolio standards (RPSs) in the United States, Korea and China have allocated quotas for renewable energy generation. Instead of an RPS, China, South America and some European countries have implemented standards for FITs, obliging power grid companies to purchase from renewable energy generators. *Example: China has been able to deploy a successful FIT for energy recovery from waste incineration. Recently, China has been in talks to introduce RPSs in the country, which will change the market to make up for renewable energy generation. However, WtE will still be a valuable commodity and will become more competitive in the market (Zhao et al., 2017).*
Zoning	Zoning controls may help local governments reduce the negative risks and impacts on the surrounding environment. These controls help implement sustainable green infrastructure because they provide a platform to evaluate the benefits and costs of the proposed infrastructure. In addition, the zoning process may appease the public's concern on infrastructure siting. Zoning mandates supporting sustainable waste infrastructure may create more demand for it. *Example: The Town and Country Planning Ordinance in Ghana has provided clear guidance on zoning functions and methods. Zoning allows for specific land-use details to be defined. In the waste management context, it allows for the identification of waste sites and disposal methods (Town and Country Planning Department, 2011).*
Bans or phase-outs	Bans and phase-outs of specific wastes can directly reduce waste generation. With strong implementation and monitoring, waste reduction methods can be highly effective. *Example: Chile became the first South American country to ban commercial businesses from using plastic bags when the new legislation was approved in August 2018. The Chilean Environment Ministry estimated that Chile uses 3.5 billion single-use plastic bags annually.*

Policy	Definition
Market Instruments and Incentives	
Taxes and tax differentiation	In the waste management context, taxes are aimed at reducing waste generation. Taxes are applied to plastic bags and landfills. Landfill taxes are usually charged by weight (similar to landfill tipping and gate fees) or using a billing rate. Local authorities may charge different taxes based on the services of the disposal type, with the incentive for waste diversion built in. *Example: Catalonia, Spain, charges higher landfill and incineration fees for waste without "biowaste" (composting) collection. Fees are EUR 10/tonne more expensive than using "biowaste" collection (R4R, 2014).*
Landfill tipping, gate fees and PAYT	Landfill tipping or gate fees are charges levied for the amount of waste received at a disposal facility. This is usually measured per tonne. European cities and municipalities have a history of implementing tipping or gate fees. Fees may also act as a source of cost recovery. Landfill or gate fees may be charged in addition to taxes. *Example: Estonia increased its annual gate fees by 700 per cent in the 10 years leading up to 2006, due to increased technical standards and operation costs. The high landfill fees are effective in reducing waste (EEA, 2009).*
Tax credits	Tax credits are used to incentivize businesses, industry and, to some extent, households to reduce their waste generation. This economic tool may be deployed to encourage research, development and implementation of more sustainable waste processing technology. Another type of tax reduction is aimed at incentivizing repairing and reusing materials. For example, value-added tax reduction can be implemented for repair services, second-hand goods and donations. *Example: Brazil introduced tax credits, regulated under Decree n. 7,619/2011, for the use of solid residues in manufacturing processes in 2010. Taxpayers are able to receive credits by utilizing recovered plastic, paper and paper cartons, glass, iron and steel, copper, nickel, aluminum, lead and zinc (Da Silva, 2015).*
Tradable pollution rights	Tradable pollution permits or rights act like a cap and trade, whereby polluters or waste generators require permits to generate and dispose of waste. These polluters: 1) are issued a set number of permits, 2) are required to purchase permits or 3) have purchased permits by auction. Polluters are then allowed to exchange permits freely with one another at a price set by either the market or the regulation authority. The system provides economic incentives to reduce waste generation or improve on the technology used to process waste. *Example: In the United Kingdom, PRNs are permits required by producers who generate over 50 tonnes of packaging material, under the Producer Responsibility Regulation, 1997. PRN obligations vary based on the different materials used for packaging. Accredited reprocessors and obligated producers are allowed to trade PRNs among each other (Valpak, 2019). South Korea has also extended its emission trading scheme to include the waste sector. This provides a new platform to expand circular economy practices (International Carbon Action Partnership, 2019).*
DRS	DRS works by collecting a small fee for a product when it is purchased, usually a recyclable container, and returning the fee when it is recycled. These systems are also known as deposit-rebate schemes. The system was developed with the aim of solving plastic waste and littering. There are many advantages to DRS, including reducing illegal dumping by providing financial incentives, easy monitoring and enforcement, and difficulty in evading cost (Walls, 2011). *Example: South Australia launched its container deposit legislation in 1977. Beverage container return rates for 2017–2018 were 78.1 per cent (South Australia EPA, n.d.)*

Policy	Definition
Information-Based Instruments	
Labelling certification	Labelling provides information about a product's origins, content and how to best dispose of it. For consumers, eco-labelling can help producers make a conscious choice to purchase products that are "green" or products that can give a tax advantage. Consumers may also have proper information about the products' disposal. On the other hand, labelling helps waste processors identify the best way to dispose of the product. *Example: Architettura Naturale (ANAB) is a certification scheme that identifies sustainable building products and furniture. ANAB products are made from renewable virgin resources and secondary resources that are recyclable. The life-cycle impact of the product is low; the products do not emit pollutants; and production of these products does not involve hazardous substances (Ecolabel Index, n.d.)*
Targeted information provision	Targeted information provision is a tool to overcome information symmetry. Information is usually provided by public or private bodies, usually having undergone review and verification. The purpose of targeted information provision is to provide individuals or businesses with better information before making decisions that have an environmental impact. *Example: The SAWIC provides access to waste management information in South Africa. SAWIC was developed by the Department of Environmental Affairs in 2005 and contains data on waste material generation, recycling, disposal and treatment. The public, businesses, industries and governments are able to access all available information on waste (SAWIC, 2005).*
Naming and shaming	Naming and shaming brands and management bodies that have contributed to poor waste management is a rising movement. The idea of the campaign is to raise awareness among consumers and producers and to hold responsible parties accountable. *Example: In the Philippines, a civic society movement assessed waste in six cities and named the top three brands behind non-recyclable waste (Libson, 2019). Governments in Jamaica and Zambia have also threatened companies that fail to abide by waste management standards with naming and shaming (Phiri, 2013; Sutherland, 2019).*
Ratings	Ratings help hold waste managers and systems accountable using a standardized system. Usually, ratings evaluate different aspects of a system or operation and allow for a holistic comparison using the standardized metrics. *Example: GreenCo E-waste Recycler Rating System was launched in 2018 in Chennai, India, to help industries transition into a sustainable e-waste recycling system. The rating system encourages monitoring, elimination of hazardous materials and inclusion of informal sectors. Stakeholders were consulted thoroughly over a year before the rating was developed and launched (Sustainable Recycling Industry, 2018).*

Policy	Definition
Support Mechanisms	
Capacity building	Capacity-building support is crucial to integrating sustainable waste infrastructure into a sustainable waste management system, especially in countries with limited institutional capacity. Examples of support include building on the technical skills of waste workers, developing infrastructure capacity and exchanging best practices to improve the existing waste system. *Example: Kenya's National Environmental Management Agency set up an e-waste recycling network connecting the Kenyan recycling market with other East African markets. In Kenya, the WEEE Centre and the East African Compliant Recycling Company have helped to facilitate development to increase the capacity of environmentally safe and economically sustainable e-waste processing and management. This includes providing technical and managerial training (Modak et al., 2015).*
Financing	A main challenge in implementing sustainable waste infrastructure is the financing gap. Waste management systems are expensive for municipalities and cost recovery is not guaranteed. Therefore, financing institutions and policies are important in developing a sustainable waste management system and cost mechanism. Policies that allow for public–private partnerships and development finance institutions help increase the feasibility of such projects. *Example: The local government of Sikasso, Mali, successfully constructed a high-tech sanitary landfill in 2002 with financing from the Belgian and Malian governments. However, the infrastructure did not lead to an improvement in solid waste management. Therefore, Sikasso authorities had to re-evaluate their solid waste management services to ensure financial accessibility and sustainability. The solution was to implement a Solid Waste Tax and beneficiary collection fees. To make the cost-recovery transition, the local authorities received a transitional subsidy of USD 3.7 million from the Global Partnership on Output-Based Aid to make the improvement (World Bank Group, 2014).* *On the other hand, established countries have dedicated funds to meet infrastructure finance gaps. In New Zealand, the government set up the Waste Minimisation Fund in 2015 to promote waste reduction and recovery. The fund is financed by a waste disposal levy that amounts to NZD 10 million–12 million per year. Of 171 projects, 60 are sustainable waste infrastructure (New Zealand Ministry for the Environment, n.d.)*
Knowledge sharing	Knowledge-sharing mechanisms are important for exchanging best practices and ideas for capacity building. Governments may invest in hosting platforms for information exchange via research, academic institutions and more. More international knowledge building platforms on waste management services can be found on the Sustainable Development Goal Knowledge Platform. *Example: The Japan International Cooperation Agency Research Institute (JICA-RI) was founded in 1998 as a research arm of governmental agency JICA, to coordinate Official Development Assistance of Japan. Japan has helped various African countries promote waste infrastructure, in line with achieving the Sustainable Development Goals (Yamamoto, 2019). They have published a report on solid waste management in developing countries that identified capacity development gaps (JICA, 2005).*
Intragovernmental coordination	Intragovernmental coordination is important in agenda-setting and policy alignment for policy implementation. A general strategy or a directive helps set agendas, but an action plan coordinates approaches to achieve the specific objectives and targets under these directives. In the case of the EU, the EC has been pushing for transitions into a circular economy design to promote sustainable growth, improve competitiveness and create jobs (EC, 2015b). *Example: In 2015, the EC adopted the EU Action Plan for the Circular Economy (EC, 2019d) with the objective of transitioning into a circular economy. The actions within the plan focused on "closing loops" of material streams within a product's life cycle to prevent waste material generation. Their targets included a 65 per cent recycling rate by 2035, as well as a binding landfill reduction target of 10 per cent of municipal waste by 2035. The package was delivered in full by March 2019, with policy tools that will continue to be in effect. Some of the targets under the action plan include investment contributions, end-of-waste criteria, recycling targets, eco-labelling and more.*

Policy	Definition
Voluntary Mechanisms	
Voluntary regulations	Voluntary regulations are agreements between a group of actors on a standard, target or goal to be achieved. These may be initiated on a number of platforms, ranging from voluntary standards within the private industry to transboundary agreements. Self-regulation may fall into this category, where an actor chooses to apply standards to themselves rather than having to agree upon group standards. *Example: In 2007, Singapore's National Environment Agency passed the Singapore Packaging Agreement (SPA). In 2017, the agency followed up with mandatory reporting of packaging waste and waste reduction. The SPA is a voluntary initiative established between the government, industry and NGOs with the goal of reducing packaging waste. The government monitors the product packaging using benchmarks and rewards companies that have taken the initiative to reduce waste generation (Singapore National Environment Agency, 2019).*
Covenants and negotiated agreements	Covenants and negotiated agreements are arrangements between the government or a public authority with a group pertaining to waste management strategies. These agreements are usually initiated by the government with businesses or groups to achieve a particular target, some of which may carry sanctions. *Example: The Irish government launched its Gum Litter Taskforce (GLT) in 2007 as part of an agreement between the chewing gum industry and the public to reduce gum litter. To achieve their objective, the private industry finances promotional and educational material on proper gum disposal, including hosting a website, point of sale initiatives, research and development of less adhesive gum and annual media campaigns. During the 2015–2017 campaign cycle, the GLT obtained a EUR 9.6 million commitment from industry. Gum as a proportion of litter has dropped from 15 per cent in 2016 to 8 per cent in 2017. The GLT is currently in its fourth campaign cycle (Department of Communications, Climate Action and Environment, 2019; Fingal County Council, 2018).*
Civic regulation	Civic or community-based regulations are carried out to monitor the performance of the private sector or government in their waste management efforts. This organized form of monitoring can be efficient when calling out the poor performances of waste management systems and grey infrastructure with negative externalities. They act as pressure groups and promote public awareness at the same time. *Example: Shanghai Rendu Ocean NPO Development Center launched its Coastal Waste Civilian Monitoring Project in 2014. The project detects and monitors marine waste, with an objective to provide "a scientific basis for marine debris management and policy making." In 2015, they established 12 monitoring sites. They aim to increase the number of sites to 50 by the end of 2050 (China Development Brief, 2019; GlobalGiving Foundation, n.d.)*
Extended producer responsibility (EPR)	EPR is a strategy to hold producers responsible for the treatment and/or disposal of a product at its end-of-life stage. The strategy puts in place incentives to promote recycling, reusing and employing appropriate disposal methods. Producers across the value chain (upstream and downstream) may be held responsible for their products' life-cycle impacts in order to induce waste prevention in the design stage. EPR may be implemented as part of mandates and negotiations or may be voluntary. *Example: South Africa has successfully implemented EPR programs, both voluntary and mandatory. The government has found more success in its voluntary EPR scheme, which targets metal packaging. Working with a mining company and a packaging company, the government mobilized supporting legislation, as did the private sector, mobilizing appropriate technology to recover up to 72 per cent of metal cans across the country (Wilson et al., 2015).*

5.0 Actors Involved

Several actors are involved in designing and implementing sustainable materials management, all with different roles.

- **Governments:** National regulators play a crucial role in establishing a framework to approach the implementation of sustainable waste infrastructure. Regional and city authorities are responsible for waste management systems, especially for municipal solid waste (MSW). As policy-makers, they are intrinsic to making the transition into sustainable material management infrastructure. Governments also have the power to participate in networks and coalitions to elevate responsible material management in a locality.

> Example:
>
> Lithuania prepared their National Strategic Waste Management Plan in 2002 to meet the EU's legislative requirements on solid waste management. To meet their objectives, Lithuania planned for nine regions to have mechanical biological treatment plants (RECO, 2013).

- **Private sector:** The sector provides technological solutions and can adopt sustainability measures in manufacturing processes. The private sector can also bridge the materials management infrastructure financing gap. Currently, the world has a USD 15 trillion investment gap in infrastructure across all sectors (Infrastructure Outlook, 2018; NERA, 2015).

> Example:
>
> Public-private partnerships have helped to improve the feasibility of sustainable material management infrastructure projects. Public-private partnerships are contractual agreements between the government and private entities to design, build, operate and/or maintain infrastructure. The United Kingdom has developed a robust public–private partnership model with its Private Finance Initiative. The initiative has created confidence and trends in increasing public-private partnerships (Deloitte, 2006). In May 2019, a number of waste management companies in the United Kingdom pledged up to GBP 10 billion in recycling infrastructure (Ogden, 2019).

- **Academia:** Data, research and development gaps can be addressed with the help of research and academic institutions to reinforce the implementation of sustainable waste management solutions. Academic institutions have also been involved in developing technology for sustainable material management.

> Example:
>
> The South African government invests in waste research, development and innovation. In 2012, they spent approximately ZAR 13 million in research, development and innovation and ZAR 344 million in human capital development. This has encouraged waste-related scientific publications in South African institutions. However, these numbers are still low because there is no money funnelled to encourage waste and material-related research (Department of Science and Technology, 2013).

- **NGOs:** NGOs have the ability to put pressure on decision-makers, to ensure that the material management process is transparent and all relevant stakeholders have been consulted. Additionally, NGOs may advocate for marginalized or disenfranchised communities in the material management process. Some NGOs and community-based organizations (CBOs) may provide educational material or waste management services in areas that do not have access to these services.

> Example:
>
> In Khulna, Bangladesh, there is limited capacity in the solid waste management system. The Khulna City Corporation (KCC) is in charge of the operations of MSW services, along with other municipal services. However, KCC has a unique makeup, whereby NGOs and CBOs operate within the KCC structure. NGOs and CBOs are in charge of door-to-door waste collection services. Waste will then be placed in a community bin for official pickup and transfer to ultimate disposal sites. NGOs and CBOs also provide support to informal waste workers, providing access to healthcare and education for this community (Ahsan et al., 2012).

- **Individuals:** The consumer base drives demand for sustainable measures in goods and services. Individual inputs are also important in the provision of appropriate waste management services.

> Example:
>
> The individual consumer is an important driving force for market demand and response. Consumer-facing businesses and homes contribute to at least 80 per cent of food waste in the United States, amounting to about 52 million tonnes per year. The calculated economic benefit for consumers is USD 5.6 billion annually, approximately USD 17.31 per capita per annum (ReFED, 2016a).

6.0 Measurement Standards and Data

6.1 Indicators Used to Measure Performance

To measure the performance of material management infrastructure or systems, material flows need to be clearly defined. Performance indicators should be embedded in each step of the material management process to allow monitoring and transparency in the system. The steps should follow that outlined in the waste hierarchy of Section 2, Figure 2: prevention, reduction, recycling, recovery and disposal.

The common indicators that measure sustainability performance are portrayed in Table 5.

Table 5. Examples of indicators for each main stage of material management

	Stage of material management	Indicator
Upstream	Production	• Resource consumption rate (material use kg per capita); raw material consumption (% of resource input) • Domestic material consumption (% of resource input) • Durability or lifetime of product compared to industry average (years) • Generation of hazardous waste in production process (g)
	Reduction	• Waste per capita (MSW per capita kg per year) • Waste generated (metric tonnes per day, TPD) • Material footprint per dollar spent
	Collection	• Waste collected and transported to disposal site (TPD) • Waste captured by the system (% MSW generated handled completely by system)
	Sorting and recovering	• Proportion of waste separated (% of waste collected) • Time and number of necessary tools for disassembly of product
	Repurposing, reusing, remanufacturing, refurbishing	• Share of remanufacturing business in manufacturing economy (%)
	Recycling	• Recycling rate (% of total MSW generated) • Proportion of recycled material in new products (%) • Share of materials with recycling options (%) • Turnover of key recyclables
Downstream	Disposal	• Proportion of waste disposed in (sanitary) landfill (% of total waste collected)

Source: EEA, 2016; UNEP, 2011; Wilson et al., 2015.

A number of waste management concepts may incorporate these indicators to evaluate the performance of waste infrastructure and management systems. However, to measure the impact or effect of introducing sustainable material management infrastructure and systems, other indicators and assessments are needed. The main types of assessments that include indicators for assessing the sustainability of materials and waste management are included in Table 6 (Allesch & Brunner, 2014). Other assessments include material flow accounts and urban metabolism (Pincetl et al., 2012; Wilson et al., 2015). These assessments may produce indicators for externalities that are reduced by sustainable material management infrastructure, like carbon dioxide avoided per amount of waste diverted from landfilling (kilotonnes CO_2) and energy intensity of product production (Wilson et al., 2015).

Table 6. Different assessment methods

Assessment method	Description
Benchmarking	Benchmarking is a continual comparison of products, services, methods or processes to identify performance gaps, with the goals to learn from the best and to note out possible improvements (Gabler, 2014).
Cost benefit analysis (CBA)	The essential theoretical foundations of CBA are defining benefits as increases in human wellbeing (utility) and costs as reductions in human wellbeing. All benefits are converted to monetary units. The cost component is the other part of the basic CBA equation (Pearce et al., 2006).
Cost effectiveness analysis (CEA	CEA evaluates alternatives according to both their cost and their effect concerning producing some outcome (Levin and McEwan, 2000). CEA allows the consideration of intangible effects.
Eco-efficiency analysis (Eco-Eff)	Eco-efficiency analysis (Eco-Eff) denotes the ecological optimization of overall systems while not disregarding economic factors. The Eco-Eff analysis by BASF quantifies the sustainability of products and processes, considering the environmental impacts and economic data concerning a business or national economic level (Saling et al., 2002).
Emergy analysis (EA)	Emergy is the amount of available energy that is used up in transformations, directly and indirectly for a service or product. The EA is an evaluation method that considers both environmental and economic values (Song et al., 2012; Yuan et al., 2011).
Environmental impact assessment (EIA)	EIA is a method that has to be performed before consent is given to a project. Significants effects on the environment by virtue, inter alia, of their nature, size or location are made subject to a requirement for development consent and for an assessment concerning their effects (Directive 2011/92/EC).
Exergy analysis	The exergy method evaluates the qualitative change from the available energy to the unusable one in the form of work (Hiraki and Akiyama, 2009; Szargut, 2005).
Life cycle assessment (LCA)	LCA addresses the environmental aspects and potential environmental impacts (e.g. use of resources and environmental consequences of releases) throughout a product's life cycle, from raw material acquisition through production, use, end-of-life treatment, recycling and final disposal (ISO, 2006).
Life cycle costing	LCC is an economic analysis method in combination with LCA. This method is a tool for accounting the total costs of a product or service over a long life span (Carlsson Reich, 2005; Langdon, 2007).

Assessment method	Description
Multi-criteria-decision-making (MCDM)	MCDM is a decision-making tool that facilitates choosing the best alternative among several alternatives. This tool evaluates a problem by comparing and ranking different options and by evaluating their consequences according to the criteria established (Hermann et al., 2007; Hung et al., 2007; Karmperis et al., 2013).
Risk assessment (RA)	RA is an integral part of the overall organization's performance assessment and measurement system for departments and for individuals. The goal is to provide a comprehensive, fully defined and fully accepted accountability for risks (ISO 2009).
Statistical entropy analysis	The statistical entropy analysis is a method that quantifies the power of a system to concentrate or to dilute substances (Brunner and Rechberger, 2004; Rechberger and Brunner, 2002).
Strategic environmental assessment (SEA)	SEA is a method to provide a high level of protection to the environment and to contribute to the integration of environmental considerations into the preparation and adoption of plans and programs, with an aim to promote sustainable development by ensuring that an environmental assessment of certain plans and programs, which are likely to have significant effects on the environment, is performed (Directive 2001/42/EC).

Source: Reprinted with permission from Allesch & Brunner 2014.

Guidance on understanding material flows and identifying points of intervention for a circular economy design have been published by governments and organizations alike. Some examples of guidelines include reports and books produced by the Ellen MacArthur Foundation, material flow measurement guidelines by the OECD and circular economy tools released by the European Commission.

6.2 Existing Sustainability Standards

Waste management infrastructure and systems may choose to adopt waste standards. The standards are either applicable to sustainability practices in industrial processes, regional waste management practices or waste infrastructure operations.

WASTE MANAGEMENT SYSTEMS

- ASTM International: waste standards for local governments
- ISO: waste standards for different waste types and packaging standard
- GRI: waste disclosure standards for private industry
- EnergyStar: waste benchmarking and reporting
- EEA: indicators for waste generation and recycling in Europe under the Waste Framework Directive
- Sustainable Development Goals: indicators for material minimization and reduction. See Goal 12 indicators.

7.0 Data

The data section is organized to approach material management systems with an overview of waste generation and material flows across different regions, steps of material management systems, impacts and types of infrastructure.

7.1 Waste Material Generation

7.1.1 Overall Generation

The world generated 2.01 billion tonnes of waste material in 2016 (Kaza et al., 2018). The Waste Atlas estimates the global waste generation rate to be 1,825,463,704 tonnes per year (D-Waste, 2013). The world is expected to generate 0.155 billion to 3.4 billion tonnes of waste material by 2050 (Kaza et al., 2018; Lebreton & Andrady, 2019). Europe, Asia and the Pacific contributed to 60 per cent of the world's waste material generation, with East Asia and the Pacific region leading global generation (Kaza et al., 2018). Most of the waste comes from industrial waste, which is generated at a rate 18 times greater than MSW, at 1.68 kg/capita/day (Kaza et al., 2018).

Across income levels, high-income and upper-middle-income groups generate the most waste materials, at 683 million and 655 million tonnes per year, respectively (Kaza et al., 2018). On the other hand, low-income groups contribute to only 93 million tonnes of waste material per year (Kaza et al., 2018). The same trends of waste material generation per income were demonstrated for the mid-2000s (UNEP, 2011). World Bank data also demonstrates that waste material generation increases with higher urbanization rates in countries (Kaza et al., 2018). Table 7 demonstrates the different material management across countries with different income levels. Table 8 demonstrates the different waste generation intensities across different regions.

The World Bank has a comprehensive and robust database of waste generation worldwide. A visual of the data can be found via World Bank's 2018 report, *What a Waste 2.0* and UNEP's 2011 report on the green economy.

Table 7. Overview of material management and costs across countries of different income levels

Parameters	Units	Low-Income Countries	Middle-Income Countries	High-Income Countries
GDP	$/capita/year	<5,000[1]	5,000 to 15,000	5,000 to 15,000
Existence of national waste management regulation	%	60%[2]	84 to 89%[2]	96%[2]
Municipal waste	kg/capita/year	150 to 250	250 to 550	350 to 750
Formal collection rate of municipal waste	%	39%[2]	51 to 82%[2]	96%[2]
Informal collection rate of municipal waste	%	Highly developed, substantial volume capture, tendency to organize in cooperatives or associations	Developed and in process of institutionalization	Quasi non-existent
Disposal methods by income	%			
Open dump		93%[2]	30 to 66%[2]	2%[2]
Anaerobic digestion		0.3%[2]	2 to 10%[2]	6%[2]
Landfill		<1%[2]	<1%[2]	<1%[2]
Incineration		<1%[2]	0 to 10%[2]	22%[2]
Composting		3%[2]	18 to 54%[2]	39%[2]
Other advanced methods		<1%[2]	<1%[2]	<2%[2]
Recycling		3.7%[2]	4 to 6%[2]	29%[2]
Municipal material composition	% weight bands			
Organic/fermentables		50 to 80	20 to 65	20 to 40
Paper and cardboard		4 to 15	15 to 40	15 to 50
Plastics		5 to 12	7 to 15	10 to 15
Metals		1 to 5	1 to 5	5 to 8
Glass		1 to 5	1 to 5	5 to 8
Moisture content		50 to 80%	40 to 60%	20 to 30%
Calorific value	kcal/kg dry basis	800 to 1,100	1,100 to 1,300	1,500 to 2,700
Industrial waste generation	kg/capita/day	N.A.[2]	0.36 to 5.72[2]	42.62[2]
E-waste generation	kg/capita/day	<0.01[2]	0.01 to 0.02[2]	0.05[2]
Waste management costs by disposal type	USD/tonne			
Collection and transfer		20 to 50[2]	30 to 100[2]	90 to 200[2]
Controlled landfill to sanitary landfill		10 to 20[2]	15 to 65[2]	40 to 100[2]
Open dumping		2 to 8[2]	3 to 10[2]*	-
Recycling		0 to 25[2]	5 to 50[2]	30 to 80[2]
Composting		5 to 30[2]	10 to 75[2]	35 to 90[2]
Waste management user fees	USD per year			
Household		37[2]	47 to 52[2]	168[2]
Consumer		155[2]	173 to 235[2]	314[2]
Solid waste management as percentage of municipal budget	%	19%[2]	11%[2]	4%[2]

[1] *Lacoste & Chalmin, 2009*
[2] *Kaza et al., 2018*
* *No open dumping data for upper middle class.*

Table 8. Material generation and intensity per GDP across different regions

Sectorial Waste Material Intensity			East Asia and Pacific	Europe and Central Asia	Latin America and the Caribbean	Middle East and North Africa	North America	South Asia	Sub-Saharan Africa
GDP		USD ('000 000 000)	213,931	228,870	54,137	33,034	187,483	29,888	16,834
Agriculture	Waste material	Tonnes ('000)	4,281,339	99,538	-	55,032	153,923	153,923	-
	Intensity	Tonnes ('000)/ USD	20.013	0.435	-	1.666	0.821	5.150	-
C&D	Waste material	Tonnes ('000)	1,668,230	1,864,128	52,143	128,937	27,572	27,572	-
	Intensity	Tonnes ('000)/ USD	7.798	8.145	0.963	3.903	0.147	0.922	-
Electronic	Waste material	Tonnes ('000)	11,649	19,102	3,928	2,872	2,191	2,191	1,192
	Intensity	Tonnes ('000)/ USD	0.054	0.083	0.073	0.087	0.012	0.073	0.071
Hazardous	Waste material	Tonnes ('000)	82,453	679,173	3,113	13,519	9,140	9,140	2,075
	Intensity	Tonnes ('000)/ USD	0.385	2.968	0.057	0.409	0.049	0.306	0.123
Industrial	Waste material	Tonnes ('000)	3,784,208	57,488	-	44,063	81	81	-
	Intensity	Tonnes ('000)/ USD	17.689	0.251	-	1.334	0.0004	0.003	-
Medical	Waste material	Tonnes ('000)	695	57,011	318	3,175	292,228	292,228	919
	Intensity	Tonnes ('000)/ USD	0.0032	0.2491	0.0059	0.0961	1.5587	9.7774	0.0546
Total MSW	Waste material	Tonnes ('000)	450,607	388,288	225,713	124,158	224,294	224,294	149,000
	Intensity	Tonnes ('000)/ USD	2.106	1.697	4.169	3.759	1.196	7.504	8.851

Source: Adapted from World Bank, 2019.

7.1.2 C&D

Every day, 1.68 kg/capita of C&D waste material is generated worldwide (Kaza et al., 2018). In Europe, C&D material represents the largest material stream in the EU, at 800 million tonnes per year (Monier et al., 2017). The largest proportion of waste generated is mineral waste, aside from soils. On average, EU countries treat 92.7 per cent of their C&D material (Monier et al., 2017).

Data on C&D material in the EU can be found in the Eurostat database. Figures for C&D waste for the United States can be found via the Environmental Protection Agency.

7.1.3 Electronic

Electronic waste material is abundant, and the generation rate has increased to 44.7 million tonnes annually (Baldé et al., 2017). Proper management of electronic waste material can lead to significant carbon emission reductions. In 2016, the estimated loss of value in raw e-waste materials was EUR 55 billion (Baldé et al., 2017). Data on e-waste material flows can be found under the International Telecommunication Union Global E-waste Monitor program.

7.1.4 Food and Other Organics

The FAO estimates that 1.3 billion tonnes of food is discarded annually (Gustavsson et al., 2011; Koester et al., 2013). Food waste represents a loss in opportunity to end global hunger and a waste of the large carbon footprint that goes into food production. Most food waste occurs in the production-to-retailing process, but the proportion of consumer-stage waste is larger for countries of higher income (FAO, 2019). Fruits, vegetables, roots and tubers represent the largest food loss sources (FAO, 2019). The latest comprehensive report on food loss with data is a 2015 report released by the FAO. The World Bank also has some country-level data on food waste. ReFED, a U.S.-based non-profit, has data on the benefits of domestic food waste diversion.

7.1.5 Healthcare

The healthcare waste material stream is made out of many different materials. The WHO estimates that 85 per cent of the materials generated are non-hazardous, with the remaining as infectious, chemical or radioactive (Chartier et al., 2014). Most waste materials generated are plastics and paper (Chartier et al., 2014). The breakdown of healthcare waste material generation rates can be found via a paper by Minoglou, Gerassimidou and Komilis (2017). The 2014 report from WHO also has material composition of healthcare waste generation (Chartier et al., 2014).

7.1.6 Biomass and Agriculture

As the world's population increases, so does the demand for and production of food. The OECD and the FAO predict that agriculture production will increase by 15 per cent by 2028 (OECD-FAO, 2019). Data for different regions are available in separate, region-focused reports by the OECD and the FAO. Statistics on agriculture have been compiled by the OECD.

7.1.7 Metals

Data on metal recycling can be found in a status report by UNEP and the International Resource Panel. OECD released a report on upstream and downstream production data on primary and secondary sector metal usage. Data on metal material management in the United States has been recorded by the U.S. EPA.

7.1.8 Material Streams

Material streams are less aggregated and more difficult to track than waste categories. However, some sources provide a breakdown of different products and materials within a waste material category. The U.S. EPA has an overview of a number of materials, including plastics, paper and metal, in different waste streams. Other countries and regions also provide a breakdown of material streams in different waste material categories, like the EU, Australia and the United Kingdom.

7.2 Shortcomings of BAU

7.2.1 Pollution

Both sustainable and unsustainable material management infrastructures can generate pollution. However, properly managed sustainable infrastructures greatly reduce pollution and thus the external costs related to pollution (Jamasb & Nepal, 2010). The main forms of pollution include emissions from standing waste stock or waste processing. Standing landfills may release GHGs like methane (CH_4) and carbon dioxide (CO_2), which will be discussed in another section. The incineration process produces carbon dioxide, particulate matter (PM), sulphur oxides (SO_x), nitrogen oxides (NO_x), volatile organic carbon (VOC) and more. Pollutant emissions are summarized in Table 9. Shadow prices for the environmental cost of pollution have also been calculated over different studies (Dijkgraaf & Vollebergh, 2004; Rabl et al., 2008).

Table 9. Emissions across different material management infrastructures

Infrastructure	CO_2	CO	HC	NO_x	N_2O	CH_4	PM	Hg	Pb	SO_x	VOCs
	kg per tonne (* indicates CO_2 equivalent)	Euro per tonne	Euro per tonne	Euro per tonne	Euro per tonne	Euro per tonne	Euro per tonne	Euro per tonne	Euro per tonne	Euro per tonne	Euro per tonne
Collection and transfer											
Sorting facilities											
Material recovery facilities											
Composting facilities											
Biowaste composting											
Mixed waste composting											
Recycling facilities	271[3]										
Anaerobic digestion	13.61*[5]										
Waste to Energy											
RDF											
Pyrolysis											
Gasification											
Combustion	2,599[3] 170–200*[6]			223–1,416[1]		229–913[2]	8,868–56,877[1]			0.50–2.30[1]	0.21–0.52[1]
Landfill				223–1416[1]		229–913[2]	233–1,486[1]			0.50–2.30[1]	0.21–0.52[1]
Landfill gas recovery											
Sanitary landfill											
Transportation		0.004 per km[4]	0.004–0.008 per km[4]	0.002–0.008 per km[4]			0.006–0.008 per km[4]				

Sources: [1]Dijkgraaf & Vollebergh, 2004, Table 4; [2]Enviros Consulting Limited, 2004, Table 4.12; [3]Ibid., Table 5.3; [4]Ibid., Table 5.3; [5]Gradus, Nillesen, Dijkgraaf, & van Koppen, 2017, Table 1; [6]Kim & Jeong, 2017; [7]ICLEI, 2013, Equation 4.1; [8]UK DEFRA, 2011, Figure 3.

7.2.2 Health

UK DEFRA calculated health impacts resulting from material management pollution, with recommended estimates for deaths, cancers, birth defects and admissions for respiratory and cardiovascular problems in the United Kingdom. Deaths brought forward were estimated to be GBP 3,100 to 110,000 (Enviros Consulting Limited, 2004)

The cost of health effects from pollution has also been calculated. For the U.K., data is available via Enviros Consulting. For the EU, cost estimation is available via the EC.

7.2.3 GHG Emissions

GHG emissions vary across different material management infrastructure. The Intergovernmental Panel for Climate Change guidelines for national GHG inventories provides guidance and conversion factors to calculate the total GHG emissions across different facilities. Incineration facilities and landfills may emit more GHGs compared to the other structures, as shown in Table 9. Combustion facilities may emit 2,599 kg/tCO_2, and landfills emit 0.015 MtCO_2e per tonne of turning compost (Gradus et al., 2017; ICLEI, 2013). Different material composition of waste may result in different GHG emissions from recycling, incineration or landfill treatments (Chen & Lin, 2008; Hillman et al., 2015; ICF International, 2016; Turner et al., 2015). GHG emissions from different materials can be found in Table 7.

Emission calculation guidance for each material management infrastructure can be found in Volume 5 of the 2019 refinement to the 2006 Intergovernmental Panel for Climate Change guidelines. The ICLEI–Local Governments for Sustainability USA have also released a protocol on recycling and composting emission estimates.

Table 10. Carbon dioxide and equivalent emissions from materials under different material management treatments

Materials	Landfill	Reuse (preparation)	Closed-loop recycling	Energy recovery (combustion)	Energy recovery (anaerobic digestion)	Composting	Incineration
	kg CO_2e/tonne	kg CO_2e/tonne	kg CO_2e/tonne	kg CO_2e/tonne	kg CO_2e/tonne	kg CO_2e/tonne	kg CO_2e/tonne
Paper	1,690[1]; 580[2]		(157)[2]	(529)[2]			
Organic (food, drink and garden waste included)	720[1]; 663[2]			(152)[2]	(281)[2]	(81)[2]	
Textiles	300[2]	(14,369)[2]		600[2]			
Aluminum cans and foil	21[2]			31[2]			
Steel cans	21[2]			31[2]			
Wood	12,701[1] 792[2]	(599)[2]	(381)[2]	(817)[2]		285[2]	
Average plastic rigid	34[2]		271 kg CO_2 per tonne[4]; 166 kg CO_2 per tonne[3]	1,057[2]			2,820 kg CO_2 per tonne[3]; 2,599 kg CO_2 per tonne[4]
Average plastic film	34[2]		same as above[3]	1,057[2]			same as above[3]
Board	580[2]		(240)[2]	(529)[2]			
Glass	26[2]			26[2]			

Sources: [1]Covec, 2007, Table 14; [2]UK DEFRA, 2011, Figure 2; [3]Gradus et al., 2017.

7.2.4 Increased Resource Stress

Globally, resource extraction rates are increasing at an average of 1.8 per cent per year to reach 10.6 per capita tonnes of resources extracted by 2020 (EMF, 2013). The OECD has predicted that materials use will increase to 167 Gt in 2060 from 79 Gt in 2011, which includes 20 Gt of metals and 86 Gt of non-metallic minerals (OECD, 2018). Even though material intensity is projected to decrease due to technological improvements, the global economy is projected to quadruple by 2060, which will lead to a net increase in material use of 1.5 per cent (OECD, 2018).

7.2.5 Decreased Economic Productivity

Environmental degradation, as a result of waste-related pollution, can cause decreased economic productivity in the form of lost income from the tourism and fisheries industry. A travel cost study in South Africa demonstrated that cleaner beaches were valued at ZAR 150,000 to ZAR 1 million (Ballance, Ryan, & Turpie, 2000). Another study estimated that beaches with more than 15 items per m^2 would result in a reduction of 39.1 per cent in income, or USD 8.5 million annually (Krelling et al., 2017). Other qualitative studies have shown that clean beaches drive tourism or are prioritized in areas with many tourists (Botero et al., 2017; Williams et al., 2016). In the fisheries industry, Palau estimated that financial losses due to terrestrial pollution, including solid waste materials, may add up to USD 88,720 per year (Hajkowicz et al., 2006). Little data and projections are available for the fisheries industry in relation to solid material management.

7.3 Benefits of Green Material Management

7.3.1 Reduction of Carbon Footprint

Proper management of waste material can reduce carbon emissions by recycling components of products. The difference in GHG emissions between secondary production and primary production of materials is the highest for aluminum (10.6 kg CO_2e/kg) (Hillman et al., 2015). Electronic materials that are recycled may avoid up to 5.00 tCO_2e/tonne of product (desktop and portable laptop computers) (Lakhan, 2016).

The reduction of carbon footprint may be calculated by examining GHG emissions across different material management facilities (Chen & Lin, 2008). There are no standard conversion factors across different facilities. However, life-cycle assessments have established that sustainable material management infrastructure and processing methods result in carbon emission reductions (Borodin et al., 2015; Cherubini et al. 2009; Edwards et al., 2018). For example, 1 kg of PET bottle waste releases 3.33 kg CO_2e via recycling, 47 kg CO_2e via landfilling and 4.3 kg CO_2e via incineration (Borodin et al., 2015).

For unsustainable material management structures like unsanitary landfills, post-closure care may be required. Sustainable material management infrastructures may reduce the costs of post-closure care. In China, post-closure care, including leachate collection and treatment, was priced at USD 0.65 m^3 (Zhou et al. 2015).

7.3.2 Resource and Cost Savings

The EC projected that a circular economy design would bring net savings of EUR 600 billion and reduce annual GHG emissions by 2–4 per cent (EC, 2015a). Statistics on material generation and savings in Europe can be found on Eurostat. Data for other countries has been compiled by the World Bank, under their What a Waste Global Database.

There are no estimates for how much material a circular economy design will save, but reports have projected cost savings based on gaps in recycling and modelling (EMF, 2013; World Economic Forum, EMF, & McKinsey & Company, 2014). Cost savings are calculated based on commodity prices and material prices of secondary materials or recyclates. The Eurostat database has prices for glass, paper and plastics. Other databases tracking commodity prices include the Global Recycling Network, Recycling Today and Kitco.

7.3.3 Green Job Creation

Green jobs within the sustainable material management sector are projected to increase, particularly under a circular economy structure. The Waste and Resources Action Programme and the Green Alliance projected job creation under a circular economy scenario using trends within the industry. In the United Kingdom, the report estimated that up to 200,000 new jobs would be created, reducing present unemployment by 54,000 by 2030 (Morgan & Mitchell, 2015).

Trends and indicators of circular economy potential can be found by examining data on the rate of material recycling, the current distribution of employment by sector of material management, occupational structure and the average hourly wage of material management employees by occupation. This may be done across material treatment facilities.

Data on material recycling may be found on a national or regional level. Currently, the European Environment Agency has produced recycling rates, as have the U.S. EPA, the United Kingdom and OECD.

Sectorial data on employment and skill requirements in the material management industry are available for the UK and the EU. The International Labour Organization also provides estimates.

Average labour requirements per sector and average wages of occupations may be found on a national level, as per the report by Morgan and Mitchell for the United Kingdom (2015). The International Labour Organization has statistics on average wages by sector. The U.S. Bureau of Labor Statistics has data by occupation and industry.

7.3.4 Employment Formalization

Sustainable material management practices will help with employment formalization, especially in developing countries or regions that do not have good management practices. Data on new job creation can be found in Section 7.3.3. Informal employment in the material management industry is difficult to monitor. Some data on the informal sector's employment, capacity and wages have been compiled in the long-standing United Nations Habitat report *Solid Waste Management in the World's Cities*.

7.4 Technology Costs, Benefits and Comparisons

The costs of all material management infrastructure are summarized in Table 8. The costs include capital and operational and management expenditures broken down into specific components, like collection and transport costs, fuel use and maintenance. Each infrastructure has a range of capital and operational costs, dependent upon the material processing capacity and economic conditions. Table 11 gives an overview of the expected public revenue generated from different material management infrastructures. This includes energy or electricity revenue generated, gate fees and taxes, and sales of co-products.

Table 11. Capital and operation and management (O&M) costs of different material management infrastructures

Infrastructure	Project Life	Capacity	Capital cost		O&M cost								Total
			Investment (* annualized)		Collection & transport costs	Labour	Fuel	Energy	Maintenance	Treatment costs	Others	Total	
	Years	Tonne/ year	Euro/tonne	Rate (%)	Euro/ tonne	Euro/ tonne	Euro/ tonne	Euro/ tonne	Euro/ tonne	Euro/ tonne	Euro/ tonne	Euro/ tonne	Euro/ tonne
Collection and transfer		4,368[1]			45–126[5]; 56[13] (mixed waste)	7 workers = 112–140 per week[1]; 14.81–54.87[12]	7.82–8.34[12]				26.74– 43.90[12] (cost of trucks and boxes/bins)	19.7[1]; 30–302[2]; 66.84–89.84[12]	
Sorting facilities					45.31–186.03[12]							183–250[2] 2; 28–272[12]	
Material recovery facilities		200,000[7]; 75,000[19]	19.70 (17, includes investment + O&M costs); 11.88–38.06 (18); 22–32[9]; 213[19]			17–118 per plant = 18.75–54.69[8]; 30 to 67 per plant = 23.79. - 51.88[9]			3.92– 5.52[9]	50.36 (clean), 58.29 (dirty)[14]		19.70 (17 inv + O&M); 50.36–58.29 (recyclables only), 65.03–66.83 (MSW + recyclables)[14]; 305.54[15]; 21.13–35.21 (no recovery)[19]	55.47– 140.63[8]
Composting facilities			9.67[3]; 20.99[5]*	7%[5]	40–178 (2, 82 is median); 98.97[3]	7 people = 13.75[5]; 5.19–23.74[9]	2.82[5]	3.54[5]	4.47[5]		5[5] (analysis and disposal of rejects)	98.97[3]; 52.92[5] (included annualized cost); 18–189[5] (across countries); 47–80[9]	72–112[9]; 79–272[11]
Biowaste composting		30,000–100,000[2]	3.97[10]		67–85[2]; 21[10]	2.80[10]			3.74[10]	76–130[2]	39–94[22] (70 median)	152[2]	
Mixed waste composting					60–85[11]						70–130[1]	142–193[2]	
Recycling facilities	291,070[14]		50.16–50.80[14]; 33,146,000[17] (total capital cost)		408[13]						269[13]	677[13]; 170.31[15]	

Infrastructure	Project Life	Capacity	Capital cost		O&M cost								Total
			Investment (* annualized)		Collection & transport costs	Labour	Fuel	Energy	Maintenance	Treatment costs	Others	Total	
	Years	Tonne/ year	Euro/tonne	Rate (%)	Euro/ tonne	Euro/ tonne	Euro/ tonne	Euro/ tonne	Euro/ tonne	Euro/ tonne	Euro/ tonne	Euro/ tonne	Euro/ tonne
Anaerobic digestion		10,000[17]	25.23[3]; 175–579[6]; 9.65[10]*; 1,228,676[17] (total capital cost); 427[19]	2.5%[10]	30.83[10]	0.93[10]; 5 people = 19.11[17]		8.41[10]; 2.55[17]				47–80.12[3]; 18.64–48.31[6]; 40.17[10]; 74.83[19]	35–109[5]; 10.7–12.20 per m^3 [17]; 258.5–500 (wet), 238.10–580.27 (dry)[19]
WtE		250,000[7]	550–800[2]; 51.23 (electricity only), 68.18 (e + heat recovery)[7] (including investment and O&M cost); 166.67–877.19[6]; 9.49–16.07[18] 226.42[27] (in China)		60[13]	1.15[27]			34.51[27]		6[13]	35–80[2]; 10.17–46.61 (electricity + heat recovery)[6]; 51.23 (electricity only), 68.18 (e + heat recovery)[7] (including capital cost); 66[13]; 54.69[17]; 6.04–30.2[18]; 12.51[27]	
RDF	36,500–109,500[20]		9.49 (Dry), 13.95 (Wet)[18]; 182 (fuel prep only)[19]; 1,553,325–5,545,522[22] (total capital cost)		3.72 per 100 km[20]	7 people = 1.05[20]		3.38[20]		253.6–329.05[16] (plastics only)		6.04 (dry), 19.5 (wet)[18]; 14.25–23.16[20]; 20.41–34.01 (no pellets)[19]	
Pyrolysis		800,000[21]; 656,000[22]	1,190[19]; 394.74 million to 582.71 million[21] (total capital cost); 216.09 million[22] (total capital cost)					0.00055[22]				115.65[19]; 106 million– 131.5 million per year[21]; 0.001[22]	
Gasification		480 MWth[23]; 376,191–708,124[25]	Same as above[19]; 336.8 million to 1,168.4 million[23] (total capital cost); 4,188–4,921 per kW[24]; 30.56–34.80[25]*; 35–45[29]	15%[25]		18.57– 19.73[25]			30–40[29]	9.28–10.44[25]	Biomass and pellet prices range from 2.89 to 8.67 per GJ and feedstock prices range from 11.72 to 46.88[24] (see Table 5.1)	Same as above[19]; average levelized cost of electricity is 0.09 to 0.22 per kWh[24]; 41.77–55.70[25]	

Infrastructure	Project Life	Capacity	Capital cost		O&M cost								Total
			Investment (* annualized)		Collection & transport costs	Labour	Fuel	Energy	Maintenance	Treatment costs	Others	Total	
	Years	Tonne/ year	Euro/tonne	Rate (%)	Euro/ tonne	Euro/ tonne	Euro/ tonne	Euro/ tonne	Euro/ tonne	Euro/ tonne	Euro/ tonne	Euro/ tonne	Euro/ tonne
Combustion			63.61[5]*; 980[19]	7%[5]						125[13] (mixed waste)	38.56[5] (operational costs independent of input, including 80 people for labour); 19.10[5] (Input dependent operational cost, including treatments)	103[4]; 12–55[5]; 105[5]; 88.44[19]	
Landfill	10[5]; 35[12]	175,000[5]; 200,000[7]; 700,000[7] (with energy recovery)	17.81[5]; 9.12[7] (including investment and O&M cost); 7.7[7] (including investment and O&M cost, energy included); 13,000,000[12] (total capital cost)		21.5–126[2]; 56.52[2]						10.97[5]	36–232[2]; 40[4]; 28.78[5]; 9.12[7] (including investment and O&M costs)	
Landfill gas recovery			7.70[7] (including investment and O&M cost); 1,327–2,655 per kW[28]; 0.8 to 1.4[29]								141.59– 247.79 per kW[28]	0.8[29]	
Sanitary landfill			23.63 per m^2 [30]								8.94 per m^2 [30] (aftercare cost)	36.66 per m^2 [30] (doesn't count aftercare cost)	

Sources: [1]Boskovic, Jovicic, Jovanovic, & Simovic, 2016 (Paper stated 19.7 Euro per tonne. Breakdown per material and detailed cost calculations available); [2]Dohogne, 2014, tables 2, 5, 6, 7, 11, 14; [3]ReFED, 2016b (for centralized composting facilities); [4]Dijkgraaf & Vollebergh, 2004, Table 2; [5]Hogg, 2001, tables 2, 11, 13, 16 (breakdown per material and cost available); [6]Kaza et al., 2018; [7]Jamasb & Nepal, 2010; [8]RRS & Steward Edge, 2012, tables 6 and 9; [9]Cimpan, Maul, Wenzel, & Pretz, 2016, tables 1 and 7; [10]Kocher, 2018, Table 7; [11]ACR+ & ACR+ Med, 2014, tables 1 and 7; [12]Covec, 2007, tables 24 and 25; [13]Gradus et al., 2017, Table 2; [14]Harris, Dick, Kim, Oliver, & Coronella, 2011, Table 16 (breakdown of landfill costs); [15]Axion Consulting, 2009, Table 13; [16]Kim & Jeong, 2017; [17]Wellinger & Wagner, 2013, sections 4.1 to 4.6; [18]Dobraja, Barisa, & Rosa, 2016; [19]Gardner, 2016, Table 10; [20]Central Public Health and Environmental Engineering Organisation, 2018; [21]Shabangu, Woolf, Fisher, Angenent, & Lehmann, 2014; [22]Wright, Satrio, Brown, Daugaard, & Hsu, 2010; [23]Holmgren, 2015; [24]International Renewable Energy Agency, 2012; [25]Klein, 2002; [26]PricewaterhouseCoopers, 2014; [27]Calixto, Thanos, Co-Advisor, & Themelis, 2017; [28]Landfill Methane Outreach Program, 2017; [29]Mutz, Hengevoss, Hugi, & Gross, 2017; [30]Pivato, Masi, De Caprio, & Tommasin, 2018.

Table 12. Revenue generated from different material management infrastructures

Infrastructure	Capacity	Revenue generated				
		Energy recovered	Landfill gate fee + tax	Sales of co-products	Others	Total
		Euro/tonne	Euro/tonne	Euro/tonne	Euro/tonne	Euro/tonne
Collection and transfer						
Sorting facilities						
Material recovery facilities			1.56–6.25[4]; 11.27–18.55 month/hh (with recycling)[10]	24.51–32.28[10]; 522.10 (plastics only)[11]		132.81–140.06[4]; 72.26–112.48[5]
Composting facilities			44[3]	9.92[3] (compost)		53.92; 12.99–15.82[8]
Biowaste composting		2.80[6]	16.81[6]			79–272 Euro per tonne (median 152) for Commercial food waste[7];31.76[6]
Mixed waste composting						140–197 (162 as mid-range)[7]
Recycling facilities			USD 17.25 per month/household[10]	628,417,266.20 – 295,622,302.20[10] (annual aggregate); 369.70[11]		677 (accounting for energy opp cost, not sales)[9]
Anaerobic digestion	170 kWh[14]	17.75[6]; 337,262[13]; 13.61[14]	9.52[6]	1.87[6]		38.30[6]; 292,526.47– 513,281.37 (not counting revenues)[13]
WtE		90[9]; 80–110[17]				66 (accounting for opportunity cost, not energy generation)[9]
RDF	800 kWh electricity or 2,600 kWh heat[14]	Up to 34.01[14]	11.71–43.90[18]	59.20–199.79 (RPF, stream sales + fuel substitution)[12]		162.88– 329.05[12]
Pyrolysis	500 kWh[14]	34.01[14]		9.77–87.22 million (biochar, annual aggregate) and 30.08 million–131.58 million (methanol, annual aggregate)[15]		
Gasification		Same as above[14]; loss of 29[16]	60.34–68.46[16]	2–5[19]		
Combustion	700 kWh[14]	21[2]; 0.02–0.05 per kWh[3]; 16.27[3]; 90[9]; 47.62[14]	76.05[1]; 12.7–44[3]; 80–110[17]	190 (RPF, stream sales + fuel substitution)[12]	3[2] (materials savings)	162.88–162.05[12]
Landfill		4[2]	25–119 Euro per tonne[1]; 5–157 Euro per tonne[7]			
Landfill gas recovery				2.4–3.4[20]		
Sanitary landfill				7.82 net revenue per m^2 [20]		

Sources: [1]Dohogne, 2014, Table 2; [2]Dijkgraaf & Vollebergh, 2004, Table 2; [3]Hogg, 2001, Table 2 (breakdown per material and cost available); [4]RRS & Steward Edge, 2012, tables 6 and 9; [5]Cimpan et al., 2016, tables 1 and 7; [6]Kocher, 2018, Table 7; [7]ACR+ & ACR+ Med, 2014, tables 1 and 7; [8]Askarany & William Franklin-Smith, 2014; [9]Gradus et al., 2017, Table 2; [10]Harris et al., 2011, Table 16; [11]Axion Consulting, 2009, Table 13; [12]Kim & Jeong, 2017; [13]Wellinger & Wagner, 2013; [14]Gardner, 2016; [15]Shabangu et al., 2014; [16]Klein, 2002; [17]PricewaterhouseCooper, 2014; [18]Calixto et al., 2017; [19]Mutz et al., 2017; [20]Pivato et al., 2018.

Table 13. Benefits of each material management infrastructure

Infrastructure	Positive								Negative			
	Diversion potential	Economic value of diverted material	Business potential	Energy savings	GHGs avoided	Jobs created	Environmental cost savings*	Time saved	Environmental cost	Disamenity	Health	Leachate
	Kilotonne/ year	Euro/tonne	Euro/tonne	Tonne/ year	Kilotonne/ year		Euro/tonne	Euro/ household/year	Euro/tonne	Euro/tonne	Euro/ tonne	Euro/ tonne
Collection and transfer												
Sorting facilities												
Material recovery facilities	50%[6]								0.47–2.65[4]			
Composting facilities	5,037[1]	3.97[1]	9.271; 53.92[5]		2,605[1]	9,000[1]						
Biowaste composting												
Mixed waste composting												
Recycling facilities								2.08[6]				
Anaerobic digestion	1,884[1]; 45%[6]	20.85[1]	22.66[1]		1,179[1]	1,933[1]						
WtE									52.55–61.67 (electricity), 30.73–40.21 (electricity + heat)[4]	8 (for incineration overall)[4]		
RDF	85% (95% if using cement kiln)[6]								57.58–257[7]			
Pyrolysis												
Gasification	75% (conventional), 95% (plasma)[6]											
Combustion	75%[6]						28.38[2]		45.95[2]; 87.95[6]; 13–90[7] (bottom + fly ash + air pollution residues treatment)	3.62–5.20[3]		
Landfill							4.21[2]		26.35[2]; 11.63–19.54[4] (no energy), 6.27–11.01[4] (w. energy)	26.36[2]; 10[4]	30.43[3]; 10[4]; 0.53–4.78[6]	0.53– 19.79[6]
Landfill gas recovery										16.27–21.01[4]	10[4]	
Sanitary landfill												

* *Environmental cost savings are avoided environmental costs through material management process*

Sources: [1]ReFED, 2016b (diversion potential for food waste); [2]Dijkgraaf & Vollebergh, 2004, Table 3; [3]Enviros Consulting Limited, 2004, Table 5.4; [4]Jamasb & Nepal, 2010; [5]Hogg, 2001, Table 11; [6]Askarany & William Franklin-Smith, 2014; [7]Gradus et al., 2017, Table 1.

8.0 An Overview of Plastics

Definition of plastics

Plastics are materials that are synthetic or semi-synthetic, lightweight, hygienic and resistant to corrosion (PlasticsEurope, n.d.; UNEP, 2018a). They have a wide range of applications. Plastics are also polymers made from natural materials like cellulose, natural gas and crude oil via polymerization or polycondensation processes (PlasticsEurope, n.d.). The two main categories of plastics are thermoplastics (i.e. PET, polystyrene) and thermosets (i.e., polyurethane, epoxy resins and silicone) (UNEP, 2018a). Plastics are commonly used as packaging material, often manufactured into a variety of products, including film, bottles, boxes and fibres (PlasticsEurope, n.d.).

Types of green plastic management infrastructure

Grey plastic management is the same as other material streams: waste is often incinerated or ends up in landfills without recovery. 36 per cent of global plastic production is composed of single-use plastics designed for disposal, equivalent to 144 million tonnes per year (UNEP, 2018a).

Sustainable plastic management infrastructure can be categorized generally as below:

- Labelling (Iceland, n.d.)
- Biodegradable plastics (van Sebille, Spathi, & Gilbert, 2016)
- Design and production infrastructure (EMF, 2016)
  - Recycled plastic inputs
  - Manufacturing infrastructure with standards
- Renewably sourced virgin feedstock (EMF, 2016)
- Sorting facilities
  - Triboelectric separation (Al-Salem, Lettieri, & Baeyens, 2010)
  - Froth flotation (Censori, La Marca, & Carvalho, 2016)
  - Magnetic density separation (Rem et al., 2013)
- Recycling facilities
  - Mechanical recycling (i.e., milling, washing and drying, agglutination and extrusion) (Al-Salem et al., 2010)
  - Chemical recycling (EMF, 2016)
- Biodegradation and anaerobic digestion (EMF, 2016)
- Composting facilities (Narancic et al., 2018)
- WtE (Bhattacharya et al., 2018)

Common indicators of plastic management infrastructure performance

- Packaging placed on market (EUROPEN, 2013)
- Plastic consumption rates (van Sebille et al., 2016)
- Plastic production rates (i.e. synthetic fibres, polymers, elastomers, performance plastics) (Singh & Sharma, 2016)
- Recycling rates (van Sebille et al., 2016)
- Recyclable plastic access rates (CM Consulting, 2017)

Life-cycle assessments have been utilized to assess the environmental impacts of plastic management processes (Healthcare Plastics Recycling Council, 2015).

Shortcomings of BAU

ENVIRONMENTAL

- Plastics may harm the marine ecosystem by injuring or killing marine wildlife, destroying habitats and bio-accumulation down the food chain (Zettl & Roberts, 2015). 8 million tonnes of plastics leak into the ocean annually and remain for a long time (EMF, 2016).
- Plastic production contributes to GHG emissions. Currently, plastic production uses 6 per cent of the oil produced worldwide (EMF, 2016). In 2012, the plastic production industry emitted 390 million tCO_2 (EMF, 2016).
- Plastics may contain hazardous substances, like bisphenol A and PVC (EMF, 2016).

ECONOMIC

- Current total natural capital cost of plastics within consumer goods amounts to more than USD 75 billion annually (UNEP, 2014).
- Lost aesthetic value and recreational opportunities incur an economic cost (van Sebille et al., 2016).

SOCIAL

- Plastic hazards to swimmers and divers (van Sebille et al., 2016).

Advantages of sustainable plastic management infrastructure

ENVIRONMENTAL

- Using recycled plastic feedstock increases resource efficiency, decreasing the reliance on fossil feedstock. Energy from materials may generate electricity and reduce fossil fuel energy use (Lazarevic et al., 2010).

ECONOMIC

- A circular economy that reuses plastic materials can save on production costs. The estimated loss of plastic packaging material is USD 80 billion–120 billion annually (EMF, 2016).

SOCIAL

- Green jobs in plastic management can be created through the implementation of sorting, recycling and monitoring aspects of plastic waste recovery. In Grenada, installing 20 collection points and a collection centre may create 25 new jobs (Zettl & Roberts, 2015).

Risks of infrastructure

Please see above for grey infrastructure risks.

Green Infrastructure Risks

MARKET

- Opting for bio-based feedstock may increase the strain on biomass resources used for plastic production and food, feed or fuel production. In the EU, conflicts between biofuels and bio-based plastics have arisen (Brodin et al., 2017).
- Initial investments are high for advanced technologies and may affect the cost of recycling. The average price of a sorting machine is EUR 300,000 (Deloitte Sustainability, 2017). Additionally, many advanced technologies are still in their infancy.
- Fluctuating supply is a key risk of using recycled plastic materials. In Europe, 60 per cent of respondents in a widely administered survey found that there is little steady and satisfactory supply (EuPC & PCE, 2019).

TECHNICAL

- Bioplastics require specific processing to be fully degraded. Thus, improper treatment may also lead to littering or BAU end-of-life disposal (Palm & Svensson Myrin, 2018).
- See example above on plastic stream contamination.

SOCIAL PRESSURE

- There is inefficiency across the value chain because of the lack of communication between manufacturers, consumers, sectors and sorting (Deloitte Sustainability, 2017).

Opportunities and challenges for plastic infrastructure implementation

Challenges:

- Changing to a renewable feedstock may incur higher costs because the availability and quality may not be as reliable as virgin and fossil inputs (Palm & Svensson Myrin, 2018).
- There are low incentives designated for appropriate plastic waste management approaches among producers and consumers (Crowe, 2019).
- Plastic recycling requires the application of specific technologies to achieve the appropriate quality. High-quality requirements for end-uses create challenges for recyclers. For example, PET recycling requires advanced optical sorters to obtain plastic fibres (Deloitte Sustainability, 2017).
- Packaging is becoming increasingly complex. Consumption rates are also increasing (Deloitte Sustainability, 2017).
- The plastic economy is still very fragmented and lacks scalable impact (EMF, 2016).
- There are no cheap alternatives for plastics, making it more difficult for individuals to switch out and away from disposable plastic (UNEP, 2018a).

Opportunities:

- Increased consumer and producer awareness on plastic waste is driving companies to increase sustainable feedstock (i.e., IKEA, DuPont, BASF) (Palm & Svensson Myrin, 2018).

Policy interventions

EPR is a key concept in plastic waste management policy approaches (OECD, 2001). Policies for plastic reduction have delegated responsibilities, which include liability, economic, physical and informative aspects (Quartey, Tosefa, Danquah, & Obrsalova, 2015). The policies below may be applied to one or more of these responsibility categories.

LEGISLATION

- See EU Waste Framework Directive 2008/98/EC, as above.
- Swedish EPR legislation obliges producers and importers of plastic packaging to collect and recycle end-of-life packaging and report statistics (Förordning om producentansvar för förpackningar [Packaging Act], 1994).

- The International Convention for the Prevention of Pollution from Ships (MARPOL 73/78) calls for a reduction in illegal dumping (International Convention for the Prevention of Pollution from Ships (MARPOL), 1973).

COLLECTION SYSTEMS

- Curbside collection systems (close proximity to households) (Quartey et al., 2015).
- Bring systems (i.e., drop-off centres, recycling stations) (Quartey et al., 2015).

Command-and-control approaches

WASTE TARGETS

- The EU has aimed to reduce plastic bags to 90 bags per person per year by 2019, and 40 bags per person per year by 2025 (Directive (EU) 2015/720, 2015).

BANS OR PHASE-OUTS OF PLASTICS

- Bangladesh banned plastics in 1995 after a series of floods clogged water infrastructure (The Bangladesh Environment Conservation Act, 1995). May be combined with levies (UNEP, 2018a).

MARKET INSTRUMENTS AND INCENTIVES

- Levies are imposed on importers, tourists and households in Grenada to cover the high cost of waste material management, as well as to prevent generation (Zettl & Roberts, 2015).
- Discounts for customers bringing personal bags in supermarket chains in Bangkok, Thailand (UNEP, 2018a).
- Tax rebates to stimulate cost-effective plastic alternatives. Antigua and Barbuda offered paper bags made from recyclables, and a list of materials to make paper were made tax free (UNEP, 2018a).

DRS

- DRS has been carried out in Kribati to reduce PET bottles and aluminum can waste by introducing container deposit legislation in 2004 (Bottle Bill Resource Guide, n.d.).

INFORMATION-BASED INSTRUMENTS

- Education (i.e., school initiatives, workshops, public radio programs) (Zettl & Roberts, 2015).
- Awareness-raising campaigns on marine litter in the Netherlands through higher educational institutions (Löhr et al., 2017). Other campaigns include international platforms like Beat the Microbead (Beat the Microbead, n.d.)

SUPPORT MECHANISMS

- Under the EU, the Horizon 2020 platform has provided more than EUR 250 million in relevant programming to its circular economy strategy, including funding plastic innovations (EC, 2018).

- Capacity-building and knowledge-sharing programs have been hosted to increase knowledge of sustainable plastic management. One such program is hosted by the Asia-Pacific Economic Cooperation (2017) on marine debris prevention and management, focusing on combatting plastic waste materials.

VOLUNTARY MECHANISMS

- See the SPA, as above (Singapore National Environment Agency, 2019).
- Public–private partnerships to generate a voluntary reduction strategy. The Austrian Federal Ministry of Agriculture, Forestry, Environment and Water Management was successful in reducing plastic carrier bags by introducing a public–private agreement to regulate bag thickness (UNEP, 2018a).
- In Bali, the initiative called Bye Bye Plastic Bags led to a Memorandum of Understanding between the public and government to phase out plastic bags by 2018 (UNEP, 2018a).
- The Alliance to End Plastic Waste is a global initiative made up of 30 companies that have committed to investing USD 1.5 billion in technology and development of plastic reduction in the production chain (Alliance to End Plastic Waste, n.d.)

Actors involved

Please see section above.

Existing sustainability standards

Guidelines on plastics

- ISO standards and methods (Singh & Sharma, 2016)
    - Specification for compostable plastics (ISO 17088:2012)
    - Guidelines for recovery and recycling of plastics waste (ISO 15270:2013)
    - Methods for the preparation and determinations (ISO 10210:2012, ISO 14855:2012)
- Indian Standard (Singh & Sharma 2016)
    - Guidelines for Recycling of Plastics (IS 14534:1998)
    - Sorting and Segregation of Plastics (IS 14535:1998)

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