

# Life Cycle of Sustainable Packaging

From Design to End of Life



Rafael A. Auras • Susan E. M. Selke



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*To our families*



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## List of Abbreviations

Abbreviation	Definition
AAGI	Annual Greenhouse Gas Index
AD	Average Dose
AFO	Animal Feeding Operation
AFPR	Alliance of Foam Packaging Recyclers
ALCA	Attributional Life Cycle Assessment
APC	Air Pollution Control
APR	Association of Packaging Recycling
AQI	Air Quality Index
ASTM	ASTM International, formerly known as American Society for Testing and Materials
ATSDR	Agency for Toxic Substances and Disease Registry
BACT	Best Available Control Technology
BF	Bioreactor Landfill
BMP	Best Management Practices
BOD	Biological Oxygen Demand
BOF	Basic Oxygen Furnace
BOPP	Biaxially Oriented Polypropylene
BPI	Biodegradable Products Institute
CAA	Clean Air Act
CAFO	Concentrated Animal Feedlot Operation
CAGR	Compound Average Growth Rate
CBW	Corrugated Board Basis Weight
CDC	Centers for Disease Control
CE	Circular Economy
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFC	Chlorofluorocarbon

CFR	Code of Federal Regulations
CHP	Combined Heat and Power
CISWI	Commercial and/or Industrial Solid Waste Incineration
CLCA	Consequential Life Cycle Assessment
COD	Chemical Oxygen Demand
CWA	Clean Water Act
DALY	Disability-Adjusted Life Years
DDT	Dichlorodiphenyltrichloroethane
DEQ	Department of Environmental Quality
DRC	Display Ready Corrugated
EDF	Environment Defense Fund
EF	Ecological Footprint
EFP	Environmental Footprint
EG	Emission Guidelines
EGLE	Department of Environment, Great Lakes, and Energy
EKC	Environmental Kuznets Curve
EPA	Environmental Protection Agency
EPCA	Environment Pollution (Prevention and Control) Authority
EPD	Environmental Product Declaration
EPR	Extended Producer Responsibility
EUROPEN	The European Organization for Packaging and the Environment
EVOH	Ethylene Vinyl Alcohol
FA	Fly Ash
FCM	Food Contact Material
FDA	Food and Drug Administration
FFDCA	Federal Food, Drug, and Cosmetic Act
FIFRA	Federal Insecticide, Fungicide, and Rodenticide Act
FLW	Food Loss and Waste
FTIR	Fourier Transform Infrared Spectroscopy
FWG	Food Waste Generation
GDP	Gross Domestic Product
GHG	Greenhouse Gas Emissions
GMA	Grocery Manufacturers Association
HAP	Hazardous Air Pollutant
HC	Hydrocarbon
HDPE	High-Density Polyethylene
HFC	Hydrofluorocarbon

HMIWI	Hospital/Medical/Infectious Waste Incineration
IPCC	Intergovernmental Panel on Climate Change
ISBM	Injection Stretch Blow Molding
ISO	International Organization for Standardization
IWLF	Industrial Waste Landfill
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
LCM	Life Cycle Management
LCRS	Leachate Collection and Removal System
LCT	Life Cycle Thinking
LCV	Lower Calorific Value
LDPE	Low Density Polyethylene
LF	Landfill
LFG	Landfill Gas
LLDPE	Linear Low Density Polyethylene
LMOP	Landfill Methane Outreach Program
MACT	Maximum Achievable Control Technology
MCL	Maximum Contaminant Level
MCLG	Maximum Contaminant Level Goals
MRDL	Maximum Residual Disinfectant Level
MRDLG	Maximum Residual Disinfectant Level Goal
MRF	Material Recovery Facility
MSU	Michigan State University
MSW	Municipal Solid Waste
MSWI	Municipal Solid Waste Incineration
MSWLF	Municipal Solid Waste Landfill
MWI	Manufacturing Waste Incinerators
NAAQS	National Ambient Air Quality Standards
NAPCOR	National Association for PET Container Resources
NDIR	Nondispersive Infrared Spectroscopy
NFP	Nutrition Facts Panel
NGO	Nongovernmental Organization
NIAS	Nonintentionally Added Substances
NIMBY	Not in My Backyard
NMOC	Nonmethane Organic Compounds
NOAA	National Oceanic and Atmospheric Administration

NOL	No Objection Letter
NPDES	National Pollution Discharge Elimination System
NSPS	New Source Performance Standards
OCC	Old Corrugated Containers
OECD	Organization for Economic Cooperation and Development
OLR	Open-Loop Recycling
ONP	Old Newspaper
OPP	Oriented polypropylene
OSWI	Other Solid Waste Incineration
PAH	Polycyclic Aromatic Hydrocarbon
PBAT	Poly(butylene adipate-co-terephthalate)
PBB	Polybrominated Biphenyls
PBT	Persistent, Bio-accumulative, and Toxic
PCB	Polychlorinated Biphenyl
PCL	Polycaprolactone
PCR	Post Consumer Recyclate
PDO	1,3-Propanediol
PE	Poly(ethylene)
PERC	Tetrachloroethene
PET	Poly(ethylene terephthalate)
PETG	Glycol-modified PET
PFAS	Per- and Polyfluoroalkyl Substances
PHA	Poly(hydroxyalkanoate)
PHB	Poly(hydroxybutyrate)
PHO	Poly(hydroxyoctanoate)
PKG	Packaging
PLA	Poly(lactic acid)
PM	Particulate Matter
PP	Poly(propylene)
PRF	Plastic Recycling Facility
PS	Poly(styrene)
PTMAT	Poly(tetramethylene adipate-co-terephthalate)
PVC	Poly(vinyl chloride)
PVDC	Poly(vinylidene chloride)
PVOH	Poly(vinyl alcohol)
RCRA	Resource Conservation and Recovery Act
RDF	Refuse Derived Fuel

RPC	Reusable Plastic Containers
RPP	Reusable Plastic Pallets
SDG	Sustainable Development Goal
SDWA	Safe Drinking Water Act
SI	Sustainability Indicators
SoP	School of Packaging
SPA	Sustainable Packaging Alliance
SPC	Sustainable Packaging Coalition
SPI	Society of the Plastics Industry
SRI	Steel Recycling Institute
TCE	Trichloroethylene
TFI	The Fertilizer Institute
TMDL	Total Maximum Daily Load
TPS	Thermoplastic Starch
TSCA	Toxic Substances Control Act
TSS	Total Suspended Solids
TVA	Tennessee Valley Authority
UFP	Ultrafine Particle
UN	United Nations
USAID	United States Agency for International Development
USCC	US Composting Council
USDA	United States Department of Agriculture
USP	US Pharmacopeia
VOC	Volatile Organic Compound
WHO	World Health Organization
WRAP	Waste & Resource Action Programme
WtE	Waste to Energy

## Preface

Packaging has become an essential instrument for sustainable development since it can guarantee protection, distribution, and safe consumption of food, medicine, and general goods. Civilization's history and development are highly intertwined with the materials used to produce packages and their construction, transportation, and commerce. From the clay amphoras used to deliver olive oil and wine across the Mediterranean during Roman and Egyptian times, to the local delivery of food in modern societies, to the freight transportation of goods from China to the USA, to the delivery of goods to the current space mission, and the future Mars exploration program, packaging has played a fundamental role in making all these enterprises possible.

Yet, the other side of packaging that has become an issue for modern society as population numbers expand is its disposal and the contamination of the environment by single-use packaging, mainly due to the lack of formal collection and waste management systems in low-income economies worldwide. As societies have become more dependent on packaging systems to guarantee their well-being and development, our relationship with packaging has become more complex, requiring a deep and all-inclusive understanding of the benefits and responsibility of implementing packaging systems.

On the journey of creating, teaching, and researching packaging systems, the soul of this book was born through a long relationship by the authors with packaging systems and their challenges and opportunities for creating packaging for sustainable development. Although it took a long time to complete this first edition, several different pieces of the work presented here are an evolution of material previously developed for several audiences in conferences and publications. In this journey, we learned that creating packaging systems for sustainable development requires a transdisciplinary approach, extensive and meaningful collaborations, and an examination of the entire life cycle of the packaging materials, processing, and end of life so that the future packaging systems can be conceived. So, to reflect on this journey and facilitate learning, we decided to organize this book so that students and teachers can learn and develop future packaging systems considering the holistic benefits and impacts they produce for society.

We start the book by providing a general framework of sustainability and circular economy related to packaging – Chapter 1. This chapter provides an available description of sustainability and the evolution of this concept, and implications for packaging. We introduce the United Nations Sustainable Development Goals (UN-SDGs) and how to create sustainable indicators for the evaluation of systems in general and in packaging. As any new packaging begins with an idea and a desire to solve a need, we continue with an invited chapter about design thinking and how to use this methodology in packaging – Chapter 2. This chapter also provides a general discussion of the tools used to create packaging systems. Since not all the readers will have training on the primary

packaging materials and the types of energy required to produce them, Chapter 3 provides a general overview of packaging materials, processing, and the energy used to make them as well as a general description of the main components of packaging systems.

In this book, we gave much attention to the concept of life cycle assessment (LCA) as the primary tool to evaluate the environmental footprint (EFP) of packaging systems; therefore, we spend several chapters building the necessary background knowledge about pollution and how to create EFP indicators. Chapter 4 defines the main criteria of pollution created by natural and anthropogenic factors and explains risk assessment and management. Chapter 5 further explores the main reasons and culprits causing soil pollution. Chapter 6 introduces the concepts of groundwater and surface water pollution. It describes the main vectors responsible for water pollution and dives into the primary US legislation regulating it. Chapter 7 discusses air pollution and examines the primary or criteria air pollutants responsible for modern air pollution. In this chapter, we also introduce the main framework of the Clean Air Act. Although most of the chapters in this section are US centered due to the regulatory bodies for soil, water, and air pollution, they apply to almost any region worldwide with some considerations. We close the section on pollution with Chapter 8 – global climate change that has become one of modern society's most significant and most concerning issues. This chapter elaborates on the primary sources of greenhouse gases and their impact on global climate. We also provide a discussion of the leading climate change agreements. After the background for dealing with pollution and creating EFP indicators are presented, we concentrate in Chapter 9 on providing a general review of LCA and the main steps to conduct a streamlined LCA when considering cradle to gate, grave, or cradle boundary conditions. This chapter also provides a general discussion of the main steps to complete an LCA according to the International Organization for Standardization (ISO) standards.

Chapter 10 introduces the concept of municipal solid waste (MSW) and the leading waste management systems for MSW – reduction, reuse, recycling, incineration with energy recovery, and residuals management. Chapter 11 expands on the reduction method of MSW and combines streamlined LCA to quantify the EFP of the reduction strategies, further focusing on the primary packaging materials (i.e., glass, metal, paper, and plastic). Chapter 12 focuses on reusing and the main scenarios and systems where reusing is beneficial, discussing how to improve them. Chapter 13 deals with recycling from the consumer, collection, and separation perspectives. Chapter 13 also includes issues about the economy and the main systems to recycle packaging materials. Chapter 14, although also considered a recycling method, deals with aerobic and anaerobic biodegradation of packaging and explores the requirements to certify a package as compostable and derived from bio-based resources. Incineration with energy recovery is an essential and growing method to deal with MSW, more in other countries than in the US, and it is discussed in Chapter 15. This chapter also discusses the main types of waste combusting units. Finally, we finish this section with Chapter 16 discussing sanitary landfills and the methods to control and deal with the pollution created by these units. The principal regulations for building and operating landfills according to the US framework are discussed.

Although not a waste management system but an important consideration when discussing packaging and its impact on current society, Chapter 17 introduces the impact of littering in the terrestrial and marine environments. It provides some relevant data mainly on the effect of littering plastics on the environment and the impact of global climate change on increasing littering in the environment. We finalize the book with Chapter 18, which we called “keeping in perspective,” where we evaluate the entire supply chain and the impact of packaging systems on the whole EFP of packaging systems and their products. We also introduce some notions of the impact between consumer perceptions and the creation of packaging for sustainable development.



As a reader, learner, or instructor of or for this book, please, feel free to combine, remove, and mix and match the chapters as they fit you and your learners since the book was written principally keeping in mind students with packaging, material science, and supply chain backgrounds. But it should be easily implemented for an array of learners with different experiences by complementing or reducing the material covered in selected chapters. We provided case studies for each chapter to help illustrate the main concepts. Still, since pollution as well as packaging are transdisciplinary sciences, the presentation of each case study can be seen and expanded using different perspectives, and we encourage that. We hope that you enjoy your time spent with this book, and please provide any feedback on how to improve it.

We want to express our gratitude to our students, who allowed us to develop and try out this material through the years. Our colleagues helped us discuss and kept us accurate to be accountable about general claims and rigorous about the calculations. Special thanks to our editorial team at Wiley for helping bring this book to life, and not least to our personal and extended packaging families that are part of this exciting journey to create a better future for society through the packaging lens. Although any book edition is imperfect, we reviewed the content several times; however, there are always fairies and goblins playing with our writing and editing process, introducing typos and mistakes, mixing with our best intentions. So, any typos and mistakes are the responsibility of the authors and the authors only.

*Rafael A. Auras and Susan E. M. Selke*

February 2022

East Lansing, MI, USA

## About the Companion Website

This book is accompanied by companion website:

[www.wiley.com/go/Auras/lifecycleofsustainablepackaging](http://www.wiley.com/go/Auras/lifecycleofsustainablepackaging)

This website includes Solution Manual and Teacher Materials



# 1

## The Role of Packaging in Sustainable Development

### 1.1 Learning Objectives

After learning from this chapter, you are expected to:

- Understand the role of packaging in social, environmental, and economic development contexts.
- Describe the main concepts of sustainability and its history.
- Understand the main areas of sustainability.
- Explain the 17 United Nations Sustainable Development Goals (UN-SDGs).
- Describe the main organization working on creating packaging for sustainable development.
- Understand the main concepts of life cycle thinking and circular economy.
- Describe the main tools designed to evaluate the environmental footprint of packaging systems.

### 1.2 Introduction

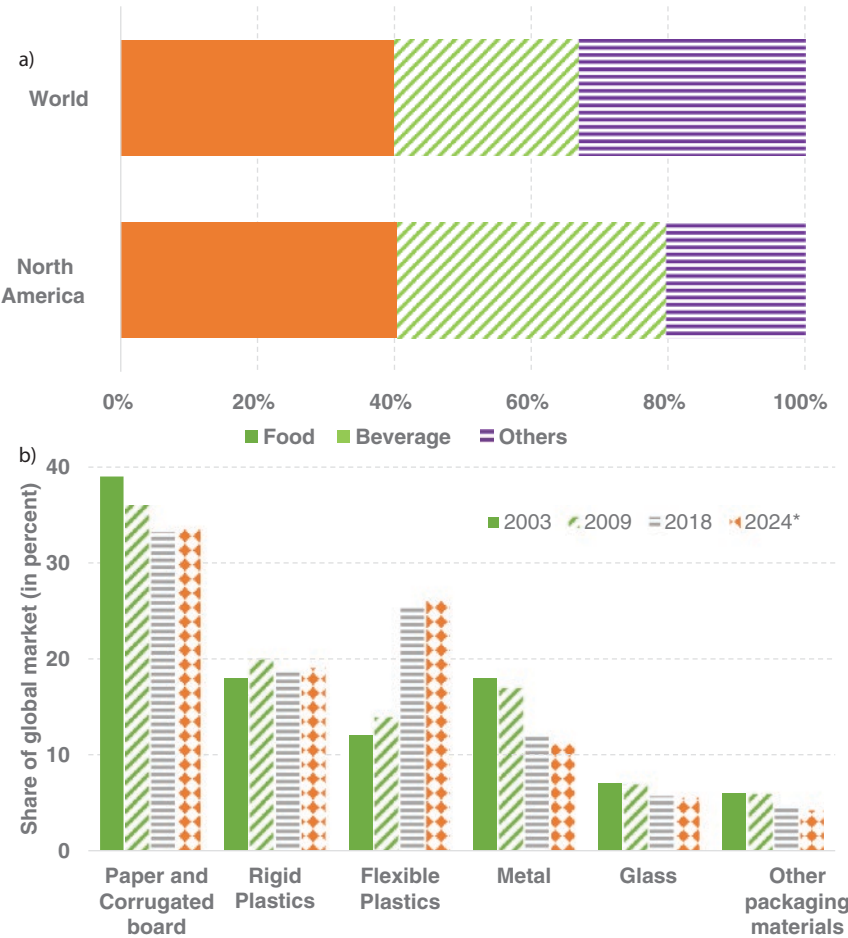
Along with the world's dramatic population growth over the past 50 years, the production of goods and services and the size of the global economy have massively increased. This exponential growth has strained our environment by increasing the levels of contaminants and the depletion of natural resources. Packaging is an essential part of valuable goods, but packaging production has environmental impacts, and packages are usually disposed of after use. This disposal contributes to environmental distress if proper recovery methods are not in place. Significant efforts have been made in optimizing packaging along the packaging value chain to reduce waste and reduce its environmental footprint. Even though continuous technology development and attitude changes have helped to reduce packaging waste, packaging and containers remain crucial to achieving sustainable systems.

### 1.3 Packaging and Sustainable Development

Packaging is a crucial component of the economy, environment, and society of any country. Packaging is highly intertwined in individuals' daily lives, helping societies transport, protect, and contain materials for producing and consuming goods. Packaging enables consumers to access products such as electronics and clean and safe medicine and food. Different packaging categories,

such as primary, secondary, and distribution packaging, have different attributes and deliver various functions. Primary and secondary packaging help the consumer to decide which product to buy, how to use it, and assist in product consumption. Distribution packaging helps to transport raw and processed materials to manufacturers for making additional goods, as well as to retailers and consumers. Although the importance of packaging and its ancillary processes and systems is not always fully understood, packaging is a crucial part of our global and circular economy. Packaging is an intrinsic component of any company, culture, and society, so it plays a vital role in any organization’s triple bottom line. Packaging created for achieving sustainable development impacts the economy, environment, and social well-being of any society.

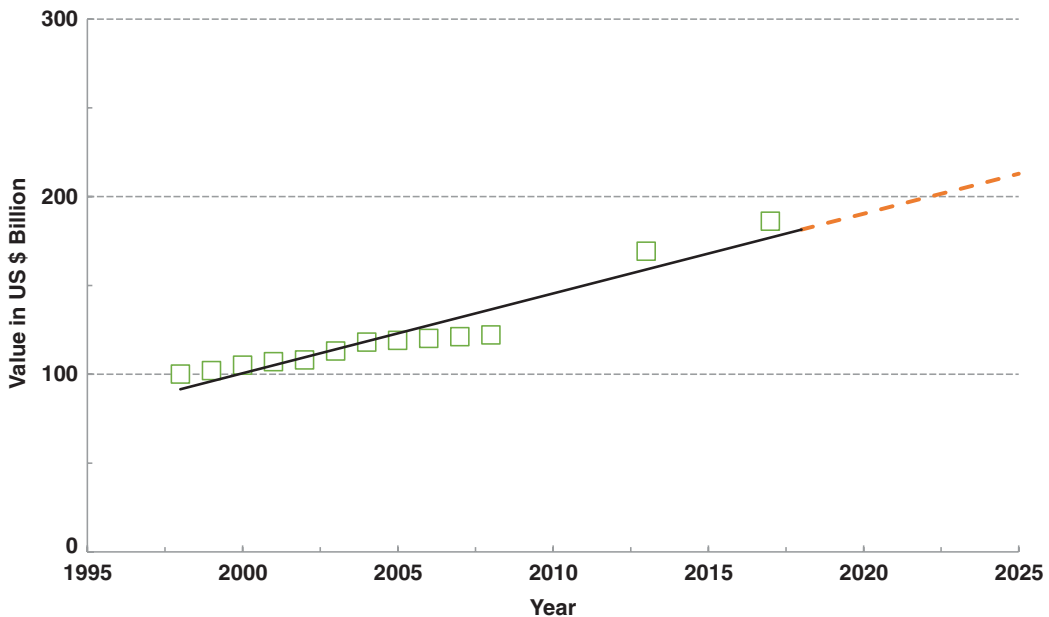
*Economy:* Packaging not only creates markets for commercializing products, but it also is the birth of industries to produce materials and their commercialization. The primary packaging materials, glass, metal, paper, and plastics, are crucial commodity materials in any economy. Packaging not only protects a product during distribution and until reaching the consumer, but it also communicates about each product. With a global packaging materials market estimated as USD 1 trillion in 2020, packaging is one of the leading economic drivers for many countries [1]. The packaging market is split evenly between food, beverage, and others, and it is composed of different materials, as shown in Figure 1.1. The North American packaging market alone in 2020



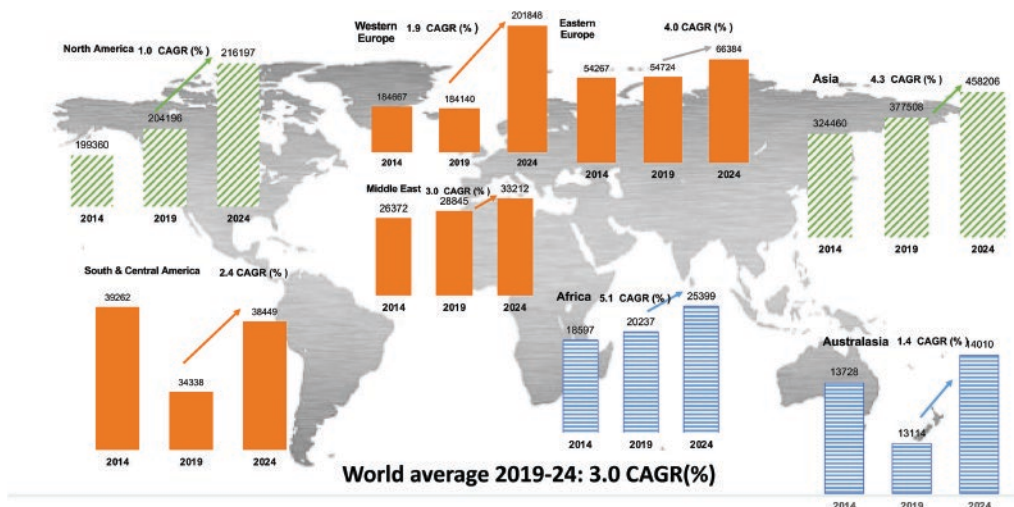
**Figure 1.1** (a) World (US\$ 1 Trillion in 2020) and North American (US\$ 180 billion) packaging market in 2020 and (b) market share of different packaging materials in the world packaging market in 2003, 2009, 2018, and \*expected in 2024, data obtained from [1].

was valued at more than \$180 billion, and it is expected to grow to more than \$220 billion by 2025 (Figure 1.2) [1]. Figure 1.3 shows that the global packaging consumption is expected to increase at a 3.0% CAGR (compound average growth rate) between 2019 and 2024, with the most significant CAGR increase in Eastern Europe, Asia, Africa, and the Middle East [1].

*Environment:* Packaging can positively and negatively impact the environment across its entire life cycle. First, during its production, it consumes resources such as land, water, and energy and creates waste. Second, it protects and contains the product during its life and communicates dietary and nutritional information. Packaging extends product shelf life. After its useful life, it can create waste and pollution if not adequately managed. The average waste generation per capita around the world was around 1.2 kg/person/day (1.3 billion tons of solid waste per year) in 2012,



**Figure 1.2** North American packaging market, values from 1995 to 2008, 2013, and 2017, and extrapolation to 2025, data obtained from [2].

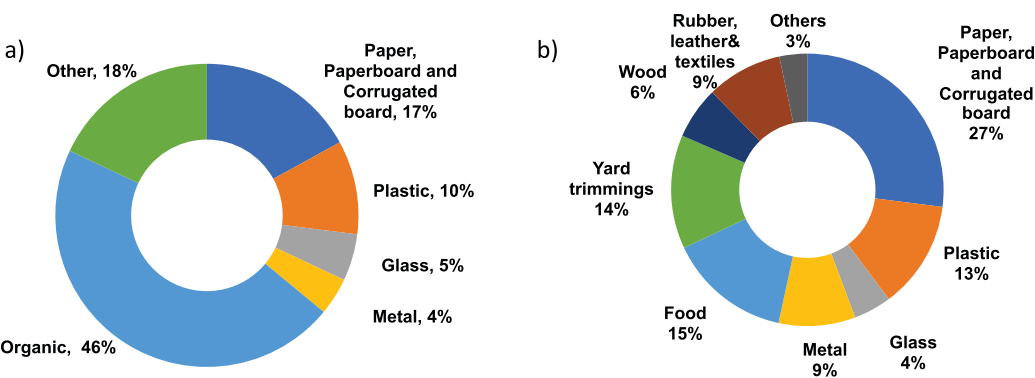


**Figure 1.3** Forecast packaging consumption by world region, 2019–2024 in \$ million, data obtained from [1].

and it is expected to grow to 1.42 kg/person/day by 2025 (2.2 billion tons of solid waste per year.) High-income-level countries generate waste even as high as 14 kg/person/day [3]. Packaging is responsible for a large part of this waste, aggravated by single-use packaging. Figure 1.4 shows the global and the United States composition of municipal solid waste (MSW). In the US, packaging and containers represent around 30% of the MSW (i.e., “commonly known as trash or garbage discarded by consumers – consists of everyday items such as product packaging, grass clippings, furniture, clothing, bottles, food scraps, newspapers, appliances, paint, and batteries”) collected in the US [4]; further discussed in Chapter 10. In addition to the amount of packaging material ending in the MSW, packaging can generate litter – white pollution – and enter the ocean creating marine pollution. Estimates for plastic waste entering the ocean range between 5 and 18 million metric tons annually, and scientists estimate 2% to 5% of the total plastic waste generated by coastal countries annually ends up in the ocean [5, 6]; further discussed in Chapter 17.

*Social.* Packaging industries can create healthy and vibrant communities, providing labor and economic growth, but they can also generate pollution, damaging humans and wildlife. It is estimated that several million people work in the packaging industry worldwide. In the US, in 2020, according to the Bureau of Labor Statistics, 49,755 people were working in Packaging and Labeling Services, 252,000 people were employed in Packaging and Filling machine operation and tenders, and around 100,000 people were employed in plastics packaging materials, film, and sheet [7]. Since the conversion of packaging raw materials and production of goods requires modest industrialization, medium and high-income countries tend to host these industries, creating benefits for their society. Scandinavian countries, the home of companies such as Tetrapack® and Ikea®, show better social performance indicators such as wealth distribution, health, and education access than many other nations, indicating that social justice and economic development are not mutually exclusive.

Furthermore, new company successes such as Apple® and Patagonia® suggest that economic performance and social responsibility are not only mutually inclusive, but they may also be correlated. Figure 1.5 shows the environmental performance index (EPI) of different countries. The EPI includes indicators for environmental health such as environmental risk exposure, air and water quality, sanitation, and ecosystem vitality such as climate and energy, biodiversity, habitat, fisheries, forests, agriculture, and water resources [8]. We can observe that high-income countries tend to have high EPI.



**Figure 1.4** (a) Global solid waste composition; adapted from [3] and (b) US municipal solid waste (MSW) composition; adapted from [4].





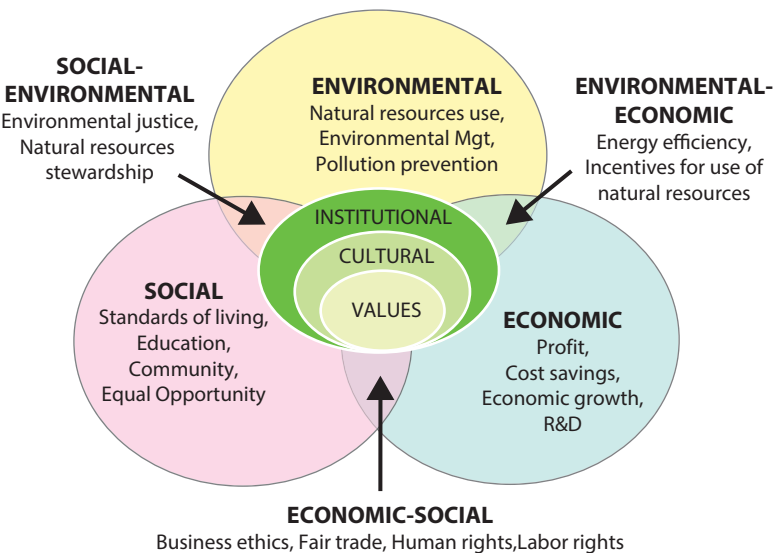
The *strong sustainability* approach means no *trade-off* between economic gain and environmental quality. Our environment is a critical resource for future generations' survival.

The *weak sustainability* approach means that environmental quality can be traded against economic gain since everything can be valued in monetary terms, including the environment.

Most of us may not be at the extreme of this sustainability spectrum, weak or strong; our beliefs and behavior toward sustainability primarily reside in between these two boundaries. Where do you fall on the spectrum? It may depend on the context of the decision, the type of decision or the action that you may be required to take. For example, you may agree to build an incineration plant in your state or hometown, but you may not be willing to live next to it – NIMBY, not in my back-yard, concept. We need to remember that opinions and decisions are easier to give and take when they are farther removed from us. This decision process is essential for environmental decisions and the implications of solid waste management facilities.

The modern concept of sustainable development came to prominence in 1987, when the United Nations' World Commission on Environment and Development, led by the former and later Norwegian prime minister Gro Harlem Brundtland, published the report *Our Common Future*, often called the Brundtland report [12], and defined sustainable development as “development that meets the needs of the present without comprising the ability of future generations to meet their own needs.” This concept is commonly illustrated in Figure 1.6, where the three main areas, social, environment, and economic, intersect. The same concept is frequently referred to as the 3-P, People, Planet, and Profit.

In the case of the US Environmental Protection Agency (US-EPA), sustainability is defined as “to create and maintain conditions, under which humans and nature can exist in productive harmony, that permit fulfilling the social, economic, and other requirements of present and future generations” [15]. The increasing interest in sustainable development advances the discussion about equity and the moral responsibility of the present society to future ones. The Brundtland report elevated the debate from the seventies from environmental issues to a more significant discussion about social equality and equity within and between generations. So, the subject of inequality found a place in policy agendas worldwide and became the subject of a much larger debate in the progress of cities, states, and countries [16].



**Figure 1.6** Schematic view of sustainable development.

## 1.5 Sustainability Timeline

This section provides an essential timeline of sustainable development. To understand how we reached the current sustainability concepts, a short tour of the main milestones in the history of sustainability helps. Table 1.1 shows a timeline of the main ideas related to the concept of sustainability since the early seventeenth century; mostly adapted from references [17, 18].

**Table 1.1** Development of the sustainability concept over time.

Century	Year	Authority	Major Ideas and/or Events	Era
17th	1627	Francis Bacon	Described the creation of a utopian land [20]	Scientific revolution
		Rene Descartes	Discourse of a Method	
		John Locke	Theory of life, liberty, and property	
		Adam Smith	Labor division	
	Early years	Jean-Jacques Rousseau	Society corrupts man	
18th	1713	Hans Carl von Carlowitz	Outlined methods for sustainable use of forests [21]	Industrial revolution, French revolution
	1798	Thomas Robert Malthus	<i>An Essay on the Principle of Population</i> [22]	
19th	1800s	B. Alcott, M. Fuller, Ralph W. Emerson	Described the natural world as a source of guidance and a mirror [17]	Transcendentalist movement
		Marry Shelley	<i>Frankenstein</i>	
	1844	Friedrich Engels	Outlines of a critique of political economy	
	1848	John Stuar Mill	Principles of Political Economy	
	1875	Karl Max	Critique of the Gotha Programme	
	Late 1800s	Gifford Pinchot	Developed a conservation ethic – Conservationism	
20th	1901	John Muir	<i>Our National Parks</i> [23]	Environmental movement
	1912		<i>The Yosemite</i> [19]	
	1949	Aldo Leopold	Land ethic [24]	
	1962	Rachel Carson	<i>Silent Spring</i> ; investigated the impact of pesticides and other industrial chemicals [25]	
	1966	Barbara Ward	<i>Spaceship Earth</i> ; discussing the impact of fine resources on Earth	
	1967	Edward Mishan	The cost of Economic Growth – GNP	
	1968	Paul and Anne Ehrlich	The population bomb	

(Continued)

**Table 1.1** (Continued)

Century	Year	Authority	Major Ideas and/or Events	Era
	1972	Donella Meadows	The limits to growth – described impact of populations, pollution, and resource consumption [26]	Contemporary Environmentalism
		United Nations	First UN Conference on the Human Environment in Stockholm, Sweden	
	1973	Cole et al.	Thinking about the future: A Critique of “The limits of Growth”	
	1973	E. Schumacher	Small is beautiful	
	1975	World Council of Churches	Concept of “Sustainable Society”	
	1977	Herman Daly	<i>Steady-State Economics</i>	
	1977	Denis Pirages	The sustainable society	
	1977–1981	Carter Administration	Renewable energy sources comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) – 1980 Superfund	Sustainability revolution
	1980	Robert Allen	How to save the world	
	1980	IUCN <sup>1</sup>	<i>World Conservation Strategy</i> [27]	
	1981	Lester Brown	<i>Building a sustainable society</i>	
	1982	United Nations	Environmental conference in Stockholm, Sweden – Sustainable development	
	1987	Gro Harlem Brundtland	<i>Our Common Future</i> [12], WCED <sup>2</sup> – meeting in 1983	
	1990	IPCC	Creation of the Intergovernmental Panel on Climate Change (IPCC) – First climate report – FAR Climate Change 1990	
	1992	United Nations	Environmental conference in Rio de Janeiro – Earth Summit 1992	
	1995	IPCC	Second climate change report – Tar Climate Change 1995	
	1997	United Nations	Earth Summit II – New York – Agenda 21	
	1997		Kyoto Protocol – Conference of the partners (COP) climate change	
	2000		The Hague Conference – COP 6	

**Table 1.1** (Continued)

Century	Year	Authority	Major Ideas and/or Events	Era
21st	2001	IPCC	Third climate change report – TAR	
	2002	United Nations	Environmental conference in Johannesburg – World Summit	
	2007	IPCC	Fourth climate change report – AR4 Climate Change 2007	
	2012	United Nations	Environmental conference in Rio de Janeiro – “Rio + 20” Earth Summit	
	2012	Ellen MacArthur Foundation	Circular Economy	
	2013	IPCC	Fifth climate change report – AR5 Climate change	
	2015	United Nations	Environmental conference in Paris – The Paris Agreement	
	2015	United Nations	Global Sustainable Development Goals – The 2030 Agenda for Sustainable Development	
	2017	US	US withdrawal from the COP agreement	
	2021	IPCC	Sixth climate change report – AR6 Climate Change 2021: The Physical Science Basis	
	2021	UN	Glasgow Climate Change Conference	

Note: <sup>1</sup>The International Union for the Conservation of Nature and Natural Resources. <sup>2</sup>The World Commission on Environment and Development.

We can divide this timeline into different eras of sustainability evolution. During the early period of the scientific revolution, the 1627 book by Francis Bacon – *The New Atlantis* – provides a description and an indication of the time to come when humans believed that *science would enable the domination of nature*. In the early eighteenth century, the Age of Enlightenment, also known as the Age of Reason, was an intellectual movement based on science and technology disseminated in Europe and North America, bringing population growth and resources to the center of the discussion. During this period, Jean-Jacques Rousseau expressed that man was born good but corrupted by society. By 1798, Malthus published his *Essay on Population* growth, where he stated that the geometric growth of population will always outgrow food supplies, creating a general concern about resources and population. In his second edition of the essay (1803), he expressed that poverty could be improved by education and delayed marriage. In the meantime, the expression of human domination of science and power was reflected in popular books such as the 1818 *Frankenstein* by Mary Shelly, which expressed humans’ obsessive quest for power. It was not until ten years after Malthus died that Friedrich Engels and Karl Marx refuted his opinion. In 1844, Engels wrote that humans could conquer nature if we used resources wisely, through science and technology, and there was no limit to growth [17]. He even went further to say that overpopulation

was an absurd concept when only one-third of Earth's land was cultivated. Marx expressed concern that poverty and misery were not due to overpopulation but oppressive economic and political structures. By 1848, John Stuart Mill, the English philosopher, published *Principles of Political Economy*, stating that profit and economic growth would decline over time as productivity limits were reached, so population growth must be restrained.

By the beginning of the twentieth century, population growth, uncontrolled use of natural resources, and weak environmental policies gave birth to the environmental movement. John Muir, a preservationist, organized the environmental movement and published his first book, *The Mountains of California*, describing the beauty of California nature and wilderness. His more significant achievements were the establishment of Yosemite National Park (1890) and leadership in the foundation of the Sierra Club. By 1910, President Teddy Roosevelt appointed the first director of the US Forest Service, Gifford Pinchot. He was known as a conservationist with a utilitarian point of view, "the greatest good for the greatest number for the longest time." Some historians and environmentalists considered this the first attempt at a sustainability definition. With Pinchot, the forestry profession was born under the precept of conservationism, and America's National Forest Service set areas of public land aside, mostly for timber production. However, forests were cultivated with one tree species to obtain the maximum amount of wood, creating biodiversity issues. The preservationists claimed that the problem with conservationism was the lack of ecologic knowledge. So, the science of ecology was born.

In the mid-1950s, reaction to overexploitation of natural resources was reflected by the work of Aldo Leopold, Rachel Carson, and Barbara Ward. Aldo Leopold (1949), in his essay *Land of Ethics* in *A Sand County Almanac*, wrote, "A thing is right when it tends to preserve the integrity, stability, and beauty of the biotic community. It is wrong when it tends otherwise." Rachel Carson (1962) published her famous book *Silent Spring* describing the unintended and unpredicted consequences of the production of dichlorodiphenyltrichloroethane (DDT) by the Michigan Chemical Company (by 1962 already owned by the Velsicol Corporation). The production and release of DDT and PBB (polybrominated biphenyls) have affected the Pine River, the St. Louis community in Michigan, and the state of Michigan even until today. A recount of this tragic story will be discussed in Chapter 6 – Case Study 6.1. Barbara Ward (1966) published *Spaceship Earth*, stating that human activity had grown to a scale where further expansion was impossible. In 1967, Edward Mishan published *The Cost of Economic Growth*. The central premise was that the calculations of Gross National Product (GNP) and Gross Domestic Product (GDP) were misleading measurements of human welfare. With the concern of global environmental limits, additional work about environmental pollution started to get attention. Paul Ehrlich (1968) published *The Population Bomb* arguing that population growth would lead to hunger, especially in Asia and overcrowded India. *The Limits to Growth* (1972), the book reporting the first computer model of population and resources, created, published, and translated into 28 languages, sold more than 9 million copies, and declared that the limit to growth on Earth would be reached in the next hundred years, creating shortages of food. Much criticism was directed at this work, mostly concentrating on its gloomy Malthusian point of view.

A new era, the sustainability revolution, started with the involvement of the United Nations. In 1972, the first UN Conference on the Human Environment took place in Stockholm, Sweden. While only two prime ministers attended the meeting, the Swedish and Indian prime ministers, it led to the creation of the United Nations Environment Programme (UNEP). The involvement of the World Council of Churches by 1975 helped to formulate the concept of a "sustainable society." However, it was not until 1977 that the first book titled *The Sustainable Society* by Denis Pirages was published, giving birth to the actual word "sustainable." In the US, new regulations such as the Clean Air Act (1963) and Clean Water Act – created in 1948 as the Federal Water Pollution Control

Act and later extensively amended in 1972, established frameworks for environmental regulations. Between 1977 and 1981, the administration of President Jimmy Carter in the US created legislation such as the Superfund act (1980), which was intended to mitigate soil, water, and land pollution.

The establishment of the World Commission on the Environment and Development (WCED) in 1983, by the UN, created the most significant statement about sustainable development when the *Our Common Future* report was published in 1987 with Gro Harlem Brundtland, former prime minister of Norway, as the chairperson. By 1990, the first Intergovernmental Panel on Climate Change (IPCC) report was published; subsequent reports were published in 1995, 2001, 2007, 2013/14, and 2021, with the IPCC winning the 2007 Nobel Peace Prize for their foundational work on quantifying the impacts of humans on climate change.

Since 1990, several UN and world summits have taken place to create a common agenda for global climate change and sustainability; among the most notable were the 1992 Earth Summit in Rio de Janeiro, Brazil; the 1997 Kyoto meeting in Kyoto, Japan, which created the Kyoto protocol, committing industrialized nations to an overall reduction of 5.2% in greenhouse gas emissions (GHG); the 2002 World Summit of sustainable development in Johannesburg, South Africa; and the 2015 Paris Agreement. During the 2015 Paris meeting, 197 countries met in Paris and acknowledged that climate change is a common concern for humankind. Hence, they agreed to reduce emissions and limit temperature rise, as stated in Article 2:

- a) Holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change;
- b) Increasing the ability to adapt to the adverse impacts of climate change and foster climate resilience and low greenhouse gas emissions development, in a manner that does not threaten food production; and
- c) Making finance flows consistent with a pathway towards low greenhouse gas emissions and climate-resilient development. [19]

By September 2017, 166 of the 197 parties entered the agreement. However, on June 1, 2017, the US, one of the two largest GHG emitting countries besides China, announced it would leave the agreement. In 2021, under the Biden administration, the US announced it was rejoining the agreement. A detailed historical and chronological description of the development of the modern sustainability concept can be found elsewhere [17, 18].

## 1.6 United Nations Sustainable Development Goals (UN-SDGs)

All UN Member States adopted the United Nations (UN) sustainability goals stated in the 2030 Agenda for Sustainable Development in 2015. The UN-SDGs – seventeen – provide a common plan for peace and prosperity for people and the planet, now and into the future. The 17 SDGs are a call for action from low- to high-income countries in a global partnership. The SDGs recognize “that ending poverty and other deprivations must go hand-in-hand with strategies that improve health and education, reduce inequality, and spur economic growth – all while tackling climate change and working to preserve our oceans and forests.” Table 1.2 and Figure 1.7 show the seventeen SDGs. A detailed description of the SDGs can be found elsewhere [28]. The Division for Sustainable Development Goals (DSDG) in the UN Department of Economic and Social Affairs provides support and capacity-building for the SDGs and their related thematic issues, including water,

**Table 1.2** United Nations 17 Goals to transform our world, targets' information; reproduced from [28].

Goal	Focus	Targets
1	No Poverty	<ul style="list-style-type: none"> <li>● “By 2030, <i>eradicate extreme poverty</i> for all people everywhere, currently measured as people living on less than \$1.25 a day.</li> <li>● By 2030, <i>reduce at least by half the proportion of men, women and children of all ages living in poverty</i> in all its dimensions according to national definitions.</li> <li>● Implement <i>nationally appropriate social protection systems</i> and measures for all, including floors, and by 2030 achieve substantial coverage of the poor and the vulnerable.</li> <li>● By 2030, ensure that all men and women, in particular the poor and the vulnerable, have <i>equal rights to economic resources</i>, as well as access to basic services, ownership and control over land and other forms of 13 property, inheritance, natural resources, appropriate new technology and financial services, including micro-finance.</li> <li>● By 2030, <i>build the resilience of the poor and those in vulnerable situations</i> and reduce their exposure and vulnerability to climate-related extreme events and other economic, social and environmental shocks and disasters.</li> <li>● Ensure significant <i>mobilization of resources</i> from a variety of sources, including through enhanced development cooperation, in order to provide adequate and predictable means for developing countries, in particular least developed countries, to implement programmes and policies to end poverty in all its dimensions.</li> <li>● Create <i>sound policy frameworks</i> at the national, regional and international levels, based on pro-poor and gender-sensitive development strategies, to support accelerated investment in poverty eradication actions.”</li> </ul>
2	Zero Hunger	<ul style="list-style-type: none"> <li>● “By 2030, <i>end hunger and ensure access</i> by all people, in particular the poor and people in vulnerable situations, including infants, <i>to safe, nutritious and sufficient food all year round</i>.</li> <li>● By 2030, <i>end all forms of malnutrition</i>, including achieving, by 2025, the internationally agreed targets on stunting and wasting in children under 5 years of age, and address the nutritional needs of adolescent girls, pregnant and lactating women and older persons.</li> <li>● By 2030, <i>double the agricultural productivity</i> and incomes of small-scale food producers, in particular women, indigenous peoples, family farmers, pastoralists and fishers, including through secure and equal access to land, other productive resources and inputs, knowledge, financial services, markets and opportunities for value addition and non-farm employment.</li> <li>● By 2030, <i>ensure sustainable food production systems and implement resilient agricultural practices</i> that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters and that progressively improve land and soil quality.</li> <li>● By 2020, <i>maintain the genetic diversity of seeds, cultivated plants and farmed and domesticated animals</i> and their related wild species, including through soundly managed and diversified seed and plant banks at the national, regional and international levels, and promote access to and fair and equitable sharing of benefits arising from the utilization of genetic resources and associated traditional knowledge, as internationally agreed.</li> <li>● <i>Increase investment</i>, including through enhanced international cooperation, in rural infrastructure, agricultural research and extension services, technology development and plant and livestock gene banks in order to enhance agricultural productive capacity in developing countries, in particular least developed countries. Correct and prevent trade restrictions and distortions in world agricultural markets, including through the parallel elimination of all forms of agricultural export subsidies and all export measures with equivalent effect, in accordance with the mandate of the Doha Development Round.</li> <li>● Adopt measures to ensure the proper functioning of food commodity markets and their derivatives and facilitate timely access to market information, including on food reserves, in order to help limit extreme food price volatility.”</li> </ul>



Table 1.2 (Continued)

Goal	Focus	Targets
3	Good Health and Well-Being	<ul style="list-style-type: none"> <li>● “By 2030, <i>reduce the global maternal mortality ratio</i> to less than 70 per 100,000 live births.</li> <li>● By 2030, <i>end preventable deaths of newborns and children under 5 years of age</i>, with all countries aiming to reduce neonatal mortality to at least as low as 12 per 1,000 live births and under-5 mortality to at least as low as 25 per 1,000 live births.</li> <li>● By 2030, <i>end the epidemics</i> of AIDS, tuberculosis, malaria and neglected tropical diseases and combat hepatitis, water-borne diseases and other communicable diseases.</li> <li>● By 2030, <i>reduce by one third premature mortality</i> from non-communicable diseases through prevention and treatment and promote mental health and well-being.</li> <li>● Strengthen the prevention and treatment of substance abuse, including narcotic drug abuse and harmful use of alcohol.</li> <li>● By 2020, <i>halve the number of global deaths</i> and injuries from road traffic accidents.</li> <li>● By 2030, ensure <i>universal access to sexual and reproductive health-care services</i>, including for family planning, information and education, and the integration of reproductive health into national strategies and programmes.</li> <li>● Achieve <i>universal health coverage</i>, including financial risk protection, <i>access to quality essential health-care services and access to safe, effective, quality and affordable essential medicines and vaccines for all</i>.</li> <li>● By 2030, substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water and soil pollution and contamination.</li> <li>● Strengthen the implementation of the World Health Organization Framework Convention on Tobacco Control in all countries, as appropriate.</li> <li>● Support the research and development of vaccines and medicines for the communicable and noncommunicable diseases that primarily affect developing countries, provide access to affordable essential medicines and vaccines, in accordance with the Doha Declaration on the TRIPS (Trade-Related Aspects of Intellectual Property Rights) Agreement and Public Health, which affirms the right of developing countries to use to the full the provisions in the Agreement on Trade Related Aspects of Intellectual Property Rights regarding flexibilities to protect public health, and, in particular, provide access to medicines for all.</li> <li>● Substantially increase health financing and the recruitment, development, training and retention of the health workforce in developing countries, especially in least developed countries and small island developing States.</li> <li>● Strengthen the <i>capacity of all countries</i>, in particular developing countries, for early warning, risk reduction and management of national and global health risks.”</li> </ul>
4	Quality Education	<ul style="list-style-type: none"> <li>● “By 2030, ensure that <i>all girls and boys complete free, equitable and quality primary and secondary education</i> leading to relevant and Goal-4 effective learning outcomes.</li> <li>● By 2030, <i>ensure that all girls and boys have access to quality early childhood development, care and preprimary education</i> so that they are ready for primary education.</li> <li>● By 2030, ensure equal access for all women and men to affordable and quality technical, vocational and tertiary education, including university.</li> <li>● By 2030, substantially increase the number of youth and adults who have relevant skills, including technical and vocational skills, for employment, decent jobs and entrepreneurship.</li> <li>● By 2030, <i>eliminate gender disparities in education and ensure equal access to all levels of education and vocational training for the vulnerable, including persons with disabilities, indigenous peoples and children in vulnerable situations</i>.</li> <li>● By 2030, ensure that all youth and a substantial proportion of adults, both men and women, achieve literacy and numeracy.</li> <li>● By 2030, ensure that <i>all learners acquire the knowledge and skills needed to promote sustainable development</i>, including, among others, through education for sustainable development and sustainable lifestyles, human rights, gender equality, promotion of a culture of peace and non-violence, global citizenship and <i>appreciation of cultural diversity</i> and of culture’s contribution to sustainable development.</li> </ul>

(Continued)



Table 1.2 (Continued)

Goal	Focus	Targets
5	Gender Equality	<ul style="list-style-type: none"> <li>● <u>Build and upgrade education facilities that are child, disability and gender sensitive and provide safe, nonviolent, inclusive and effective learning environments for all</u></li> <li>● By 2020, substantially expand globally the number of scholarships available to developing countries, in particular least developed countries, small island developing States and African countries, for enrolment in higher education, including vocational training and information and communications technology, technical, engineering and scientific programmes, in developed countries and other developing countries.</li> <li>● By 2030, substantially increase the supply of qualified teachers, including through international cooperation for teacher training in developing countries, especially least developed countries and small island developing states.”</li> </ul>
		<ul style="list-style-type: none"> <li>● “End all forms of discrimination against all women and girls everywhere.</li> <li>● Eliminate all forms of violence against all women and girls in the public and private spheres, including trafficking and sexual and other types of exploitation</li> <li>● Eliminate all harmful practices, such as child, early and forced marriage and female genital mutilation.</li> <li>● Recognize and value unpaid care and domestic work through the provision of public services, infrastructure and social protection policies and the promotion of shared responsibility within the household and the family as nationally appropriate.</li> <li>● Ensure women’s full and effective participation and equal opportunities for leadership at all levels of decision making in political, economic and public life.</li> <li>● Ensure universal access to sexual and reproductive health and reproductive rights as agreed in accordance with the Programme of Action of the International Conference on Population and Development and the Beijing Platform for Action and the outcome documents of their review conferences.</li> <li>● Undertake reforms to give women equal rights to economic resources, as well as access to ownership and control over land and other forms of property, financial services, inheritance and natural resources, in accordance with national laws.</li> <li>● Enhance the use of enabling technology, in particular information and communications technology, to promote the empowerment of women.</li> <li>● Adopt and strengthen sound policies and enforceable legislation for the promotion of gender equality and the empowerment of all women and girls at all levels.”</li> </ul>
6	Clean Water and Sanitation	<ul style="list-style-type: none"> <li>● “By 2030, achieve universal and equitable access to safe and affordable drinking water for all.</li> <li>● By 2030, achieve access to adequate and equitable sanitation and hygiene for all and end open defecation, paying special attention to the needs of women and girls and those in vulnerable situations.</li> <li>● By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally.</li> <li>● By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity.</li> <li>● By 2030, implement integrated water resources management at all levels, including through transboundary cooperation as appropriate.</li> <li>● By 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes.</li> <li>● By 2030, expand international cooperation and capacity-building support to developing countries in water- and sanitation-related activities and programmes, including water harvesting, desalination, water efficiency, wastewater treatment, recycling and reuse technologies.</li> <li>● Support and strengthen the participation of local communities in improving water and sanitation management.”</li> </ul>

Table 1.2 (Continued)

Goal	Focus	Targets
7	Affordable and Clean Energy	<ul style="list-style-type: none"> <li>● “By 2030, ensure <u>universal access to affordable, reliable and modern energy services</u>.</li> <li>● By 2030, increase substantially the share of renewable energy in the global energy mix.</li> <li>● By 2030, double the global rate of improvement in energy efficiency.</li> <li>● By 2030, <i>enhance international cooperation</i> to facilitate access to clean energy research and technology, including renewable energy, energy efficiency and advanced and cleaner fossil-fuel technology, and promote investment in energy infrastructure and clean energy technology.</li> <li>● By 2030, expand infrastructure and upgrade technology for supplying modern and sustainable energy services for all in developing countries, in particular least developed countries, small island developing States, and land-locked developing countries, in accordance with their respective programs of support.”</li> </ul>
8	Decent Work and Economic Growth	<ul style="list-style-type: none"> <li>● “<i>Sustain per capita economic growth</i> in accordance with national circumstances and, in particular, at least 7 per cent gross domestic product growth per annum in the least developed countries.</li> <li>● Achieve higher levels of economic productivity through diversification, technological upgrading and innovation, including through a focus on high value added and labor-intensive sectors.</li> <li>● <i>Promote development-oriented policies</i> that support productive activities, decent job creation, entrepreneurship, creativity and innovation, and encourage the formalization and growth of micro-, small- and medium-sized enterprises, including through access to financial services.</li> <li>● Improve progressively, through 2030, global resource efficiency in consumption and production and endeavor to decouple economic growth from environmental degradation, in accordance with the 10-year framework of programs on sustainable consumption and production, with developed countries taking the lead.</li> <li>● By 2030, <i>achieve full and productive employment and decent work for all women and men, including for young people and persons with disabilities, and equal pay for work of equal value</i>.</li> <li>● By 2020, substantially reduce the proportion of youth not in employment, education or training.</li> <li>● Take immediate and effective measures to eradicate forced labor, end modern slavery and human trafficking and secure the prohibition and elimination of the worst forms of child labor, including recruitment and use of child soldiers, and by 2025 end child labor in all its forms.</li> <li>● Protect labor rights and promote safe and secure working environments for all workers, including migrant workers, in particular women migrants, and those in precarious employment.</li> <li>● By 2030, devise and implement policies to promote sustainable tourism that creates jobs and promotes local culture and products.</li> <li>● Strengthen the capacity of domestic financial institutions to encourage and expand access to banking, insurance and financial services for all.</li> <li>● Increase Aid for Trade support for developing countries, in particular least developed countries, including through the Enhanced Integrated Framework for Trade-Related Technical Assistance to Least Developed Countries.</li> <li>● By 2020, <i>develop and operationalize a global strategy for youth employment</i> and implement the Global Jobs Pact of the International Labor Organization.”</li> </ul>
9	Industry, Innovation and Infrastructure	<ul style="list-style-type: none"> <li>● “<i>Develop quality, reliable, sustainable and resilient infrastructure</i>, including regional and transborder infrastructure, to support economic development and human well-being, with a focus on affordable and equitable access for all.</li> <li>● <i>Promote inclusive and sustainable industrialization</i> and, by 2030, significantly raise industry’s share of employment and gross domestic product, in line with national circumstances, and double its share in least developed countries.</li> <li>● Increase the access of small-scale industrial and other enterprises, in particular in developing countries, to financial services, including affordable credit, and their integration into value chains and markets.</li> <li>● By 2030, <i>upgrade infrastructure and retrofit industries to make them sustainable</i>, with increased resource-use efficiency and greater adoption of clean and environmentally sound technologies and industrial processes, with all countries taking action in accordance with their respective capabilities.</li> </ul>

(Continued)

Table 1.2 (Continued)

Goal	Focus	Targets
10	Reduced Inequality	<ul style="list-style-type: none"> <li>● Enhance scientific research, upgrade the technological capabilities of industrial sectors in all countries, in particular developing countries, including, by 2030, encouraging innovation and substantially increasing the number of research and development workers per 1 million people and public and private research and development spending.</li> <li>● <i>Facilitate sustainable and resilient infrastructure development</i> in developing countries through enhanced financial, technological and technical support to African countries, least developed countries, landlocked developing countries and small island developing States.</li> <li>● Support domestic technology development, research and innovation in developing countries, including by ensuring a conducive policy environment for, inter alia, industrial diversification and value addition to commodities.</li> <li>● Significantly <i>increase access to information and communications technology</i> and strive to provide universal and affordable access to the Internet in least developed countries by 2020.”</li> <li>● “By 2030, progressively achieve and sustain income growth of the bottom 40 per cent of the population at a rate higher than the national average.</li> <li>● By 2030, empower and promote the social, economic and political inclusion of all, irrespective of age, sex, disability, race, ethnicity, origin, religion or economic or other status.</li> <li>● Ensure equal opportunity and reduce inequalities of outcome, including by eliminating discriminatory laws, policies and practices and promoting appropriate legislation, policies and action in this regard.</li> <li>● Adopt policies, especially fiscal, wage and social protection policies, and progressively achieve greater equality.</li> <li>● Improve the regulation and monitoring of global financial markets and institutions and strengthen the implementation of such regulations.</li> <li>● Ensure enhanced representation and voice for developing countries in decision-making in global international economic and financial institutions in order to deliver more effective, credible, accountable and legitimate institutions.</li> <li>● Facilitate orderly, safe, regular and responsible migration and mobility of people, including through the implementation of planned and well-managed migration policies.</li> <li>● Implement the principle of special and differential treatment for developing countries, in particular least developed countries, in accordance with World Trade Organization agreements.</li> <li>● Encourage official development assistance and financial flows, including foreign direct investment, to States where the need is greatest, in particular least developed countries, African countries, small island developing States and landlocked developing countries, in accordance with their national plans and programs.</li> <li>● By 2030, reduce to less than 3 per cent the transaction costs of migrant remittances and eliminate remittance corridors with costs higher than 5 per cent.”</li> </ul>
11	Sustainable Cities and Communities	<ul style="list-style-type: none"> <li>● “By 2030, ensure access for all to adequate, safe and affordable housing and basic services and upgrade slums.</li> <li>● By 2030, provide access to safe, affordable, accessible and sustainable transport systems for all, improving road safety, notably by expanding public transport, with special attention to the needs of those in vulnerable situations, women, children, persons with disabilities and older persons.</li> <li>● By 2030, enhance inclusive and sustainable urbanization and capacity for participatory, integrated and sustainable human settlement planning and management in all countries.</li> <li>● Strengthen efforts to protect and safeguard the world’s cultural and natural heritage.</li> <li>● By 2030, significantly reduce the number of deaths and the number of people affected and substantially decrease the direct economic losses relative to global gross domestic product caused by disasters, including water-related disasters, with a focus on protecting the poor and people in vulnerable situations.</li> <li>● By 2030, reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality and municipal and other waste management</li> </ul>

**Table 1.2** (Continued)

Goal	Focus	Targets
12	Responsible Consumption and Production	<ul style="list-style-type: none"> <li>● By 2030, provide universal access to safe, inclusive and accessible, green and public spaces, in particular for women and children, older persons and persons with disabilities.</li> <li>● Support positive economic, social and environmental links between urban, peri-urban and rural areas by strengthening national and regional development planning</li> <li>● By 2020, substantially increase the number of cities and human settlements adopting and implementing integrated policies and plans towards inclusion, resource efficiency, mitigation and adaptation to climate change, resilience to disasters, and develop and implement, in line with the Sendai Framework for Disaster Risk Reduction 2015-2030, holistic disaster risk management at all levels.</li> <li>● Support least developed countries, including through financial and technical assistance, in building sustainable and resilient buildings utilizing local materials.”</li> <li>● “Implement the <i>10-year framework of programs on sustainable consumption and production</i>, all countries taking action, with developed countries taking the lead, taking into account the development and capabilities of developing countries.</li> <li>● By 2030, achieve the <i>sustainable management and efficient use of natural resources</i>.</li> <li>● By 2030, <i>halve per capita global food waste</i> at the retail and consumer levels and reduce food losses along production and supply chains, including post-harvest losses.</li> <li>● By 2020, <i>achieve the environmentally sound management of chemicals and all wastes throughout their life cycle</i>, in accordance with agreed international frameworks, and significantly reduce their release to air, water and soil in order to minimize their adverse impacts on human health and the environment.</li> <li>● By 2030, <i>substantially reduce waste generation through prevention, reduction, recycling and reuse</i>.</li> <li>● <i>Encourage companies</i>, especially large and transnational companies, <i>to adopt sustainable practices</i> and to integrate sustainability information into their reporting cycle</li> <li>● <i>Promote public procurement practices</i> that are sustainable, in accordance with national policies and priorities.</li> <li>● By 2030, ensure that people everywhere have the relevant information and awareness for sustainable development and lifestyles in harmony with nature.</li> <li>● <i>Support developing countries</i> to strengthen their scientific and technological capacity to move towards more sustainable patterns of consumption and production.</li> <li>● <i>Develop and implement tools to monitor sustainable development impacts</i> for sustainable tourism that creates jobs and promotes local culture and products.</li> <li>● <i>Rationalize inefficient fossil-fuel subsidies that encourage wasteful consumption by removing market distortions</i>, in accordance with national circumstances, including by restructuring taxation and phasing out those harmful subsidies, where they exist, to reflect their environmental impacts, taking fully into account the specific needs and conditions of developing countries and minimizing the possible adverse impacts on their development in a manner that protects the poor and the affected communities.”</li> </ul>
13	Climate Action	<ul style="list-style-type: none"> <li>● “<i>Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters</i> in all countries.</li> <li>● <i>Integrate climate change measures into national policies, strategies and planning</i>.</li> <li>● <i>Improve education, awareness-raising and human and institutional capacity on climate change mitigation, adaptation, impact reduction and early warning</i>.</li> <li>● <i>Implement the commitment undertaken by developed-country parties to the United Nations Framework Convention on Climate Change</i> to a goal of mobilizing jointly \$100 billion annually by 2020 from all sources to address the needs of developing countries in the context of meaningful mitigation actions and transparency on implementation and fully operationalize the Green Climate Fund through its capitalization as soon as possible.</li> <li>● <i>Promote mechanisms for raising capacity for effective climate change-related planning and management</i> in least developed countries and small island developing States, including focusing on women, youth and local and marginalized communities.”</li> </ul>

(Continued)

**Table 1.2** (Continued)

Goal	Focus	Targets
14	Life Below Water	<ul style="list-style-type: none"> <li>● “By 2025, <i>prevent and significantly reduce marine pollution of all kinds</i>, in particular from land-based activities, including marine debris and nutrient pollution.</li> <li>● By 2020, <i>sustainably manage and protect marine and coastal ecosystems</i> to avoid significant adverse impacts, including by strengthening their resilience, and take action for their restoration in order to achieve healthy and productive oceans.</li> <li>● Minimize and address the impacts of ocean acidification, including through enhanced scientific cooperation at all levels.</li> <li>● By 2020, <i>effectively regulate harvesting and end overfishing</i>, illegal, unreported and unregulated fishing and destructive fishing practices and implement science-based management plans, in order to restore fish stocks in the shortest time feasible, at least to levels that can produce maximum sustainable yield as determined by their biological characteristics.</li> <li>● By 2020, conserve at least 10 per cent of coastal and marine areas, consistent with national and international law and based on the best available scientific information.</li> <li>● By 2020, <i>prohibit certain forms of fisheries subsidies which contribute to overcapacity and overfishing</i>, eliminate subsidies that contribute to illegal, unreported and unregulated fishing and refrain from introducing new such subsidies, recognizing that appropriate and effective special and differential treatment for developing and least developed countries should be an integral part of the World Trade Organization fisheries subsidies negotiation.</li> <li>● By 2030, <i>increase the economic benefits to Small Island developing States</i> and least developed countries from the sustainable use of marine resources, including through sustainable management of fisheries, aquaculture and tourism.</li> <li>● Increase scientific knowledge, develop research capacity and transfer marine technology, taking into account the Intergovernmental Oceanographic Commission Criteria and Guidelines on the Transfer of Marine Technology, in order to improve ocean health and to enhance the contribution of marine biodiversity to the development of developing countries, in particular small island developing States and least developed countries.</li> <li>● Provide access for small-scale artisanal fishers to marine resources and markets.</li> <li>● Enhance the conservation and sustainable use of oceans and their resources by implementing international law as reflected in UNCLOS (United Nations Convention on the Law of the Sea), which provides the legal framework for the conservation and sustainable use of oceans and their resources, as recalled in paragraph 158 of The Future We Want.”</li> </ul>
15	Life on Land	<ul style="list-style-type: none"> <li>● “By 2020, <i>ensure the conservation, restoration and sustainable use of terrestrial and inland freshwater ecosystems and their services</i>, in particular forests, wetlands, mountains and drylands, in line with obligations under international agreements.</li> <li>● By 2020, promote the implementation of sustainable management of all types of forests, halt deforestation, restore degraded forests and substantially increase afforestation and reforestation globally.</li> <li>● By 2030, <i>combat desertification</i>, restore degraded land and soil, including land affected by desertification, drought and floods, and strive to achieve a land degradation-neutral world.</li> <li>● By 2030, <i>ensure the conservation of mountain ecosystems</i>, including their biodiversity, in order to enhance their capacity to provide benefits that are essential for sustainable development.</li> <li>● <i>Take urgent and significant action to reduce the degradation of natural habitats</i>, halt the loss of biodiversity and, by 2020, protect and prevent the extinction of threatened species.</li> <li>● <i>Promote fair and equitable sharing of the benefits arising from the utilization of genetic resources</i> and promote appropriate access to such resources, as internationally agreed.</li> <li>● <i>Take urgent action to end poaching and trafficking of protected species of flora and fauna</i> and address both demand and supply of illegal wildlife products.</li> </ul>

Table 1.2 (Continued)

Goal	Focus	Targets
16	Peace and Justice Strong Institutions	<ul style="list-style-type: none"> <li>● By 2020, introduce measures to prevent the introduction and significantly <i>reduce the impact of invasive alien species</i> on land and water ecosystems and control or eradicate the priority species.</li> <li>● By 2020, <i>integrate ecosystem and biodiversity values into national and local planning, development processes, poverty reduction strategies and accounts.</i></li> <li>● Mobilize and significantly <i>increase financial resources from all sources</i> to conserve and sustainably use biodiversity and ecosystems.</li> <li>● Mobilize significant resources from all sources and at all levels to <i>finance sustainable forest management</i> and provide adequate incentives to developing countries to advance such management, including for conservation and reforestation.</li> <li>● Enhance global support for efforts to combat poaching and trafficking of protected species, including by increasing the capacity of local communities to pursue sustainable livelihood opportunities.”</li> </ul>
		<ul style="list-style-type: none"> <li>● “Significantly <i>reduce all forms of violence and related death rates</i> everywhere.</li> <li>● <i>End abuse, exploitation, trafficking and all forms of violence against and torture of children.</i></li> <li>● <i>Promote the rule of law at the national and international levels</i> and ensure equal access to justice for all.</li> <li>● By 2030, significantly <i>reduce illicit financial and arms flows</i>, strengthen the recovery and return of stolen assets and combat all forms of organised crime.</li> <li>● Substantially <i>reduce corruption and bribery</i> in all their forms.</li> <li>● Develop effective, accountable and transparent institutions at all levels.</li> <li>● <i>Ensure responsive, inclusive, participatory and representative decision-making at all levels.</i></li> <li>● <i>Broaden and strengthen the participation of developing countries</i> in the institutions of global governance.</li> <li>● By 2030, provide legal identity for all, including birth registration.</li> <li>● <i>Ensure public access to information and protect fundamental freedoms</i>, in accordance with national legislation and international agreements.</li> <li>● Strengthen relevant national institutions, including through international cooperation, for building capacity at all levels, in particular in developing countries, to prevent violence and combat terrorism and crime.</li> <li>● Promote and enforce non-discriminatory laws and policies for sustainable development.”</li> </ul>
17	Partnerships to achieve the Goal	<p>a) Finance</p> <ul style="list-style-type: none"> <li>● “Strengthen domestic resource mobilization, including through international support to developing countries, to improve domestic capacity for tax and other revenue collection.</li> <li>● Developed countries to implement fully their official development assistance commitments, including the commitment by many developed countries to achieve the target of 0.7 per cent of ODA/GNI to developing countries and 0.15 to 0.20 per cent of ODA/GNI to least developed countries ODA providers are encouraged to consider setting a target to provide at least 0.20 per cent of ODA/GNI to least developed countries</li> <li>● Mobilize additional financial resources for developing countries from multiple sources.</li> <li>● Assist developing countries in attaining long-term debt sustainability through coordinated policies aimed at fostering debt financing, debt relief and debt restructuring, as appropriate, and address the external debt of highly indebted poor countries to reduce debt distress.</li> <li>● Adopt and implement investment promotion regimes for least developed countries.</li> </ul>

(Continued)



Table 1.2 (Continued)

Goal	Focus	Targets
		<p>b) Technology</p> <ul style="list-style-type: none"> <li>● Enhance North-South, South-South and triangular regional and international cooperation on and access to science, technology and innovation and enhance knowledge sharing on mutually agreed terms, including through improved coordination among existing mechanisms, in particular at the United Nations level, and through a global technology facilitation mechanism.</li> <li>● Promote the development, transfer, dissemination and diffusion of environmentally sound technologies to developing countries on favorable terms, including on concessional and preferential terms, as mutually agreed.</li> <li>● Fully operationalize the technology bank and science, technology and innovation capacity-building mechanism for least developed countries by 2017 and enhance the use of enabling technology, in particular information and communications technology.</li> </ul> <p>c) Capacity building</p> <ul style="list-style-type: none"> <li>● Enhance international support for implementing effective and targeted capacity-building in developing countries to support national plans to implement all the sustainable development goals, including through North-South, South-South and triangular cooperation.</li> </ul> <p>d) Trade</p> <ul style="list-style-type: none"> <li>● Promote a universal, rules-based, open, non-discriminatory and equitable multilateral trading system under the World Trade Organization, including through the conclusion of negotiations under its Doha Development Agenda.</li> <li>● Significantly increase the exports of developing countries, in particular with a view to doubling the least developed countries' share of global exports by 2020.</li> <li>● Realize timely implementation of duty-free and quota-free market access on a lasting basis for all least developed countries, consistent with World Trade Organization decisions, including by ensuring that preferential rules of origin applicable to imports from least developed countries are transparent and simple, and contribute to facilitating market access.</li> </ul> <p>e) Systemic issues</p> <p><i>Policy and institutional coherence</i></p> <ul style="list-style-type: none"> <li>● Enhance global macroeconomic stability, including through policy coordination and policy coherence.</li> <li>● Enhance policy coherence for sustainable development.</li> <li>● Respect each country's policy space and leadership to establish and implement policies for poverty eradication and sustainable development.</li> </ul> <p><i>Multi-stakeholder partnerships</i></p> <ul style="list-style-type: none"> <li>● Enhance the global partnership for sustainable development, complemented by multi-stakeholder partnerships that mobilize and share knowledge, expertise, technology and financial resources, to support the achievement of the sustainable development goals in all countries, in particular developing countries.</li> <li>● Encourage and promote effective public, public-private and civil society partnerships, building on the experience and resourcing strategies of partnerships.</li> </ul> <p><i>Data, monitoring and accountability</i></p> <ul style="list-style-type: none"> <li>● By 2020, enhance capacity-building support to developing countries, including for least developed countries and small island developing States, to increase significantly the availability of high-quality, timely and reliable data disaggregated by income, gender, age, race, ethnicity, migratory status, disability, geographic location and other characteristics relevant in national contexts.</li> <li>● By 2030, build on existing initiatives to develop measurements of progress on sustainable development that complement gross domestic product, and support statistical capacity-building in developing countries."</li> </ul>



**Figure 1.7** United Nations Sustainable Development Goals (UN-SDGs); reproduced from [28] license under CC BY 4.0.

energy, climate, oceans, urbanization, transport, science and technology, the Global Sustainable Development Report (GSDR), partnerships, and Small Island Developing States. The main targets for each SDG can be found in the United Nations SDG reports.

Packaging systems can be instrumental in helping to achieve all the SDGs. For example, the packaging program at the United States Agency for International Development (USAID) works to support and provide nutritional food to needy populations, promoting a path to recipient self-reliance and resilience; this effort has a direct connection between packaging and SDGs 1, 2, 3, and 10. A direct link can also be attributed to packaging and SDG 6 – clean water by providing reusable or single-use bottles. More than 250,000 people work in the packaging industry in the US alone, which relates to SDG 8. For SDG 9, the world average compound annual growth rate between 2019 and 2024 for the packaging industry is expected to be 3.0%. Packaging is a growing industry helping people to earn a decent living. For SDG 12, new packaging systems are aligned with responsible consumption and production. Packaging industries are increasingly focusing on reducing waste generation through prevention, reduction, reuse, and recycling.

## 1.7 Sustainability Indicators (SIs)

To determine if a system, product, or package is sustainable, indicators should be assigned to each social, economic, and environmental evaluation area. Table 1.3 shows an example of popular SIs used by governments and NGOs to evaluate sustainable systems. It has been expressed that “one of the major criticisms of SIs is that they attempt to agglomerate complex and diverse problems in a few simple measures” [8]. Mostly, this is referred to as a reductionist approach, which has received criticism from many who consider that scientists and policymakers are obsessed with quantification. Biologists have used indicators to measure ecosystem health for many years, such as the Shannon-Wiener Index [29]. However, sustainability incorporates many more dimensions than the environment, such as quality of life and economic returns, and the evolution of sustainable development unquestionably leads to the quantification of sustainability.

One of the many problems of sustainability measurement is to know how many indicators for each category are enough. Bell and Morse [8] provide an excellent discussion of SIs and their



**Table 1.3** Selected examples of indicators of ecosystem health and sustainability.

Index	Initial Year	Acronyms	Source	Ref.
City Development Index	2015	CDI	United Nations Human Settlements Programme (UN-Habitat)	[30]
Ecological Footprint		EF	Weidman and Barrett	[31]
Environmental Adjusted Net Domestic Product		EDP	UN Statistics Division	[32]
Environmental Performance Index	2018	EPI	Yale and Columbia Universities	[8]
The Environmental Vulnerability Index	2004	EVI	South Pacific Applied Geoscience Commission (SOPAC), the United Nations Environment Programme (UNEP) and their partners	[33]
Genuine Progress Indicator	After 1989	GPI	Based on the Daly and Cobb (1989) and Philip Lawn work	[34]
Genuine Saving Index	2004	GSI	Economic indicator – World Bank	[35]
Harger and Meyer	1996	ESSD	Harger and Meyer, 1996	[36]
Human Development Index		HDI	Amartya, Sen and Haq, Mahbub ul	
Index of Sustainable Economic Welfare	1989	ISEW	Daly and Cobb (1990)	[37]
Inequality-adjusted Human Development Index	2020	IHDI	Human Development Report, 2020	[38]
Living Planet Index	1970	LPI	Living Planet Index 2020 Report	[39, 40]
Maximum sustainable index*	Early 1930	MSY	Russell (1931)	[41]
OECD Better Life Index	2011	WI	OECD (2021)	[42]
Shannon-Wiener Index or Diversity Index	1948	H	Shannon (1948)	[43]
Total Factor Productivity Index	1956	TFPI	Solow (1956)	[44]

\* Used mostly for fisheries.

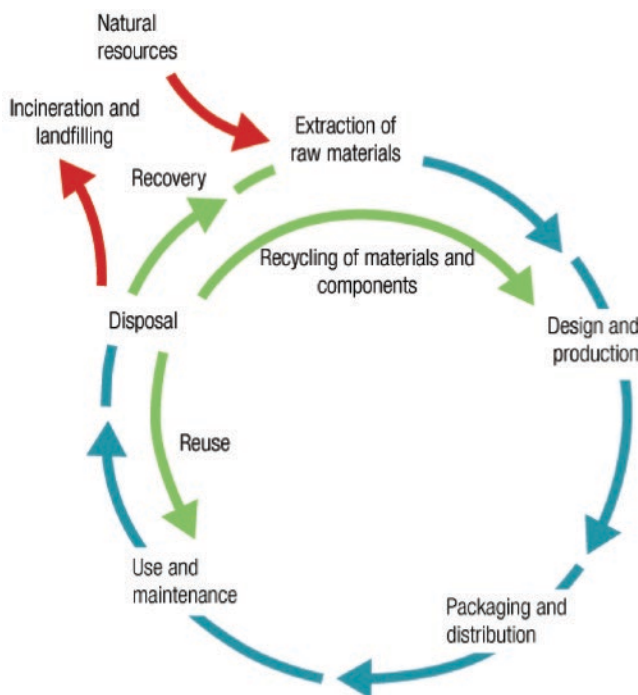
creation. Primarily, they are based on a system of indicators created to measure driving force (D) and state response (SR) (i.e., DSR), and may include some additional areas such as impact (I) -DSIR, or pressure (P) in the system to be evaluated (DSPIR). These methods are mostly based on identifying the leading indicators for each area of interest to be appraised. With the help of stakeholders, find a mechanism of determining the main indicators to be mapped in the social, economic, and environmental areas of interest. One well-known example of SI in the US is the Environmental

Performance Index (EPI), created by Yale and Columbia Universities researchers. The EPI provides a ranking on a national basis with values between 0 (most unsustainable) and 100 (most sustainable). They used a general DSIR system to gauge the sustainability of countries based on 76 variables aggregated into 22 indicators and normalized for quantification; see Figure 1.5 [8]. Although all these variables and indicators are used, as Bell and Morse [8] expressed, “SIs are still a classic reductionist set of tools based on quantification.” In general, they are a top-down approach and not stakeholder-driven methodologies.

In general, the construction of SIs is subject to many pressures, agendas, and biases. So, transparency in the process and detailed method description are the recommended procedures for SI construction and implementation.

## 1.8 Life Cycle Thinking

The criteria of life cycle thinking (LCT) are based on moving away from a linear production system to a circular one, including environmental, social, and economic impacts of a product life cycle so that the number of resources used by a product and the amount of emissions released during its production and use can be optimized. LCT also accounts for improving socioeconomic performance throughout its life cycle. So, resources can be optimized and impact minimized. Figure 1.8 shows a typical product life cycle diagram when considering LCT. A product life cycle can begin with the extraction of raw materials from natural resources in the ground and energy generation. Then,



**Figure 1.8** Life cycle thinking (LCT) is used for a product cycle.