CHAPTER 1

INTRODUCTION

Society is increasingly conscious of the importance of solid waste management (SWM) in the context of sustainable development. The need to operate our waste management activities in a way that minimizes environmental and health risks and ensures economic growth and social progress has been well received by the community. The purpose of this chapter is to emphasize the essence of sustainable development as part of the package of tools for making decisions about SWM. This chapter provides a common framework for sustainable development and relevant basic principles that support such ideas. The guidelines describe possible actions to establish a framework for a wide range of SWM activities across diverse spatial and temporal scales. Case studies that demonstrate how to apply sustainable SWM processes across a variety of activities are introduced sequentially in subsequent chapters.

1.1 THE CONCEPT OF SUSTAINABLE DEVELOPMENT

1.1.1 The Concept Formation

The book "Silent Spring" written by Rachel Carson was published in 1962 (Carson, 1962). The seemingly related connection between the insecticide applications and bird populations was considered a turning point in our basic understanding of the interconnections among the environment, the economy, and social well-being. In 1972, the United Nations Conference on the Human Environment held in Stockholm

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brought the industrialized and developing nations together to delineate the "rights" of the human family to a healthy and productive environment (United Nations, 2013). In the 1980s, human society was increasingly conscious of possible detrimental effects that its economic activities can have on ecosystems and the environment. Note that ecosystems in this context are systems of plants, animals, and microorganisms together with the nonliving components of their environment (UNEP/WWF/IUCCNF, 1980). This book adopts the definition used in the United Kingdom Environmental Protection Act 1990, that the environment "… consists of all, or any, of the following media, namely the air, water and land." Over generations, the loss of quality of life in human society can result from environmental degradation due to past economic activities, as seen in the numerous hazardous waste remediation sites across the United States (US). The "World Conservation Strategy," jointly published by United Nations Environment Programme (UNEP), World Wide Fund for Nature (WWF), and International Union for Conservation of Nature and Natural Resources (IUCNNR), noted that (UNEP/WWF/IUCCNF, 1980):

> The combined destructive impacts of a poor majority struggling to stay alive and an affluent minority consuming most of the world's resources are undermining the very means by which all people can survive and flourish. Humanity's relationship with the biosphere (the thin covering of the planet that contains and sustains life) will continue to deteriorate until a new international economic order is achieved, a new environmental ethic adopted, human populations stabilize, and sustainable modes of development become the rule rather than the exception. Among the prerequisites for sustainable development is the conservation of living resources.

The World Conservation Strategy, which provided a precursor to the concept of sustainable development, aims to (UNEP/WWF/IUCCNF, 1980):

- maintain essential ecological processes and life-support systems (such as soil regeneration and protection, the recycling of nutrients and the cleansing of waters), on which human survival and development depend;
- preserve genetic diversity (the range of genetic material found in the world's organisms), on which depend the breeding programs necessary for the protection and improvement of cultivated plants and domesticated animals, as well as much scientific advance, technical innovation, and the security of the many industries that use living resources;
- ensure the sustainability utilization of species and ecosystems (notably fish and other wildlife, forests, and grazing lands), which supports millions of rural communities as well as major industries.

The United Nations General Assembly convened in 1983 to discuss "The World Commission on Environment and Development" to address concerns about the accelerating degradation of the human environment and natural resources and the consequences of such degradation for economic and social development. Later, the concept of "sustainable development" was formalized by the Brundtland Report published in 1987. Although sustainable development has been defined in many ways, the most

frequently quoted definition is from "Our Common Future" in the Brundtland Report (WCED, 1987):

> Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs.

Two key concepts are emphasized in the Brundtland Report (WCED, 1987) as excerpted below:

- "needs," in particular the essential needs of the world's poor, to which overriding priority should be given; and
- "limitations" imposed by the state of technology and social organization on the environment's ability to meet present and future needs.

In comparison, sustainable development was defined by the President's Council on Sustainable Development in the United States as (USEPA, 2013):

> … an evolving process that improves the economy, the environment, and society for the benefit of current and future generations.

In June 1992, the first UN Conference on Environment and Development was held in Rio de Janeiro and adopted an agenda entitled "Agenda 21: A Programme of Action for Sustainable Development" (United Nations, 1992). Agenda 21 states the Rio Declaration on Environment and Development, which agrees to some 27 supporting principles that are abbreviated as the "Rio Principles." Agenda 21 reaffirmed that sustainable development was delimited by the integration of the economic, social, and environmental pillars. This understanding triggers the possible change in consumption and production patterns. Within these 27 supporting principles, principles 3, 4, 6, 8, 10, 11, 13, 14, 15, 16, and 17 are most relevant to waste management, as excerpted below (United Nations, 1992):

Principle 3: The right to development must be fulfilled so as to equitably meet developmental and environmental needs of present and future generations.

Principle 4: In order to achieve sustainable development, environmental protection shall constitute an integral part of the development process and cannot be considered in isolation from it.

Principle 6: The special situation and needs of developing countries, particularly the least developed and those most environmentally vulnerable, shall be given special priority. International actions in the field of environment and development should also address the interests and needs of all countries.

Principle 8: To achieve sustainable development and a higher quality of life for all people, States should reduce and eliminate unsustainable patterns of production and consumption and promote appropriate demographic policies.

Principle 10: Environmental issues are best handled with participation of all concerned citizens, at the relevant level. At the national level, each individual

shall have appropriate access to information concerning the environment that is held by public authorities, including information on hazardous materials and activities.

Principle 11: States shall enact effective environmental legislation. Environmental standards, management objectives, and priorities should reflect the environmental and development context to which they apply. Standards applied by some countries may be inappropriate and of unwarranted economic and social cost to other countries, in particular developing countries.

Principle 13: States shall develop national law regarding liability and compensation for the victims of pollution and other environmental damage. States shall also cooperate in an expeditious and more determined manner to develop further international law regarding liability and compensation for adverse effects of environmental damage caused by activities within their jurisdiction or control to areas beyond their jurisdiction.

Principle 14: States should effectively cooperate to discourage or prevent the relocation and transfer to other States of any activities and substances that cause severe environmental degradation or are found to be harmful to human health.

Principle 15: (Precautionary principle)—In order to protect the environment, the "precautionary approach" shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation.

Principle 16: (Polluter pay principle)—National authorities should endeavor to promote the internalization of environmental costs and the use of economic instruments, taking into account the approach that the polluter should, in principle, bear the cost of pollution, with due regard to the public interest and without distorting international trade and investment.

Principle 17: Environmental impact assessment, as a national instrument, shall be undertaken for proposed activities that are likely to have a significant adverse impact on the environment and are subject to a decision of a competent national authority.

1.1.2 The Three Pillars in Sustainable Development

In 2002, the World Summit on Sustainable Development was convened in Johannesburg to renew the global commitment to sustainable development. The conference agreed to the Johannesburg Plan of Implementation to follow up on the implementation of sustainable development. It signifies the three pillars approach to illustrate sustainability (Figure 1.1). Sustainable development seeks to achieve economic development, social welfare, and environmental protection, in a balanced manner, from which we start seeing the world as a collection of interconnected systems.

Given that the concept of sustainable development is rooted in systems thinking, definitions of sustainable development in this illustration require that the whole world

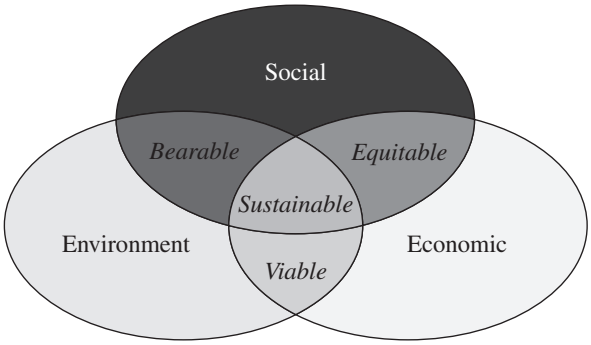

FIGURE 1.1 Three pillars approach to illustrate sustainability

be considered a system over space and time. Hence, sustainable development relies on a systems-based approach that seeks to understand the interactions that exist among the three pillars (environment, social, and economic) in an effort to better realize the unintended consequences of our actions (USEPA, 2013). The United States Environmental Protection Agency (USEPA) has an insightful list that embodies the principles of sustainability via six aspects of each pillar as excerpted below (USEPA, 2013).

1. **Environmental pillar**
   - **Ecosystem services:** Protect, sustain, and restore the health of critical natural habitats and ecosystems (e.g., potential impacts of hydraulic fracturing).
   - **Green engineering and chemistry:** Develop chemical products and processes to reduce/prevent chemical hazards, reuse or recycle chemicals, treat chemicals to render them less hazardous, and dispose of chemicals properly (e.g., life cycle environmental impacts).
   - **Air quality:** Attain and maintain air quality standards and reduce the risk from toxic air pollutants (e.g., investigate potential greenhouse gas emissions reduction strategies).
   - **Water quality:** Reduce exposure to contaminants in drinking water (including protecting source waters) in fish and shellfish and in recreational waters (e.g., pathogen removal in riverbank filtration).
   - **Stressors:** Reduce effects by stressors (e.g., pollutants, greenhouse gas emissions, genetically modified organisms) to the ecosystem (e.g., fate of modified nanoparticles in aqueous media).
   - **Resource integrity:** Reduce adverse effects by reducing waste generation, increasing recycling, and ensuring proper waste management; and restore resources by mitigating and cleaning up accidental or intentional releases (e.g., improving recycling technology to prevent environmental impact of mining).

2. **Economic pillar**
   - **Jobs:** Create or maintain current and future jobs (e.g., create green jobs).
   - **Incentives:** Generate incentives that work with human nature to encourage sustainable practices (e.g., conservation reserve program, encouraging sustainable logging practices).
   - **Supply and demand:** Promote price or quantity changes that alter economic growth, environmental health, and social prosperity (e.g., increasing supply of green energy sources to reduce the need for fossil fuels).
   - **Natural resource accounting:** Incorporate natural capital depreciation in accounting indices and ecosystem services in cost–benefit analysis (CBA) (e.g., green net national product).
   - **Costs:** Positively impact costs of processes, services, and products (e.g., strive to develop a waste-free process for eliminating the need for regulation costs).
   - **Prices:** Promote a cost structure that accounts for externalities to production (e.g., bottle bill—beverage container deposit laws) throughout the United States and around the world).
3. **Social pillar**
   - **Environmental justice:** Protect health of communities over-burdened by pollution by empowering them to take action to improve their health and environment (e.g., establish partnerships with local, state, tribal, and federal organizations to achieve healthy and sustainable communities).
   - **Human health:** Protect, sustain, and improve human health (e.g., parameterize the model to predict developmental toxicology).
   - **Participation:** Use open and transparent processes that engage relevant stakeholders (e.g., develop database of reduced-risk pesticides for commonly used products, create greater public access and understanding about sustainability).
   - **Education:** Enhance education on sustainability to the general public, stakeholders, and potentially affected groups (e.g., provide opportunities for students to learn about sustainability).
   - **Resource security:** Protect, maintain, and restore access to basic resources (e.g., food, land, and energy, and study impacts of dispersants/oil combination on natural water ways).
   - **Sustainable communities:** Promote the development, planning, building, or modification of communities to promote sustainable living (e.g., landscape with native plant species, construct "green" buildings).

1.1.3 Temporal and Spatial Characteristics of Sustainability Goal

Sustainable development concurrently addresses both spatial and temporal characteristics that must be clearly defined from local, regional, and global viewpoints for current and future generations. Sustainability concerned with intergeneration equity

may link with a larger time scale than the life cycle of a product, technology, or treatment plant. The time frame employed for project evaluation should be extended to the same time horizon to meet sustainability implications. Long-term projects involve higher complexity and wider ranges of scenarios with uncertainty. This might also be true for time-dependent technology innovation, development, and improvement. Residents who live in the proximity of these developments bear more pollution impact than those farther away, however, and environmental justice may be a sustainability concern from the societal point of view. Sustainability in this regard may be linked with varying spatial scales depending on the types of pollutants of concern. Integrating both spatial and temporal characteristics may generate higher uncertainty anyhow. Assessment of uncertainties and their consequences require a deeper level of risk assessment, which becomes an essential component of sustainability analysis.

1.1.4 The Possible Actions to Achieve the Sustainability Goal

In 2012, United Nations published "Review of Implementation of Agenda 21 and the Rio Principles," which outlined areas that would need to be addressed to enable more rapid progress toward the objectives set during the Rio Earth Summit 20 years earlier. The detailed reviews of Agenda 21 and the Rio Principles and the submission from Stakeholder Forum to the Rio conference (United Nations, 2012) offer some perspectives for action in these areas.

1. **Progressing and protecting human development**
   - **A rights-based approach:** Human development requires having a true rights-based approach to coping with various welfare, well-being, and environmental issues that are essential to sustainable development.
   - **Increasing participation:** All people have the basic right to receive environmental information, participate in transparent decision-making processes, and access judicial and administrative proceedings.
   - **Giving a voice to future generations:** The future needs of next generations are a crucial element of sustainable development; but they are not represented in the relevant decision-making processes.
2. **Sustainable management of the Earth**
   - **Acknowledge environmental limits:** There is an acute need to formally realize key environmental thresholds within which we must count on for our livelihood and to maintain the ecosystem sustainability of our planet.
   - **Sustainable management of natural resources and capitals:** All levels of government should ensure that their accounting efforts may address not only the GDP but also the state of natural assets and ecosystems and their role in sustaining human and economic activity.
3. **The green economy**
   - **Beyond gross domestic product (GDP):** GDP is an indicator of success that is the current reliance on economic growth in most of the developing

countries. This tendency has led to perverse outcomes due to the ignorance of environmental sustainability. A new economic indicator that has correction of environmental costs may better justify the true outcomes.

- **Fiscal reform:** Taxes or other policy instruments should be used to motivate positive behavior and discourage undesirable behavior.
- **Restart a meaningful conversation about the role of corporations in the achievement of sustainable development:** Conversations could take the form of a "Convention on Corporate Social Responsibility" to improve the producer's responsibility.

4. **Sustainable institutions and governance**
   - **Sustainable development goals:** The inclusion of sustainable development goals is a possible foundation for building international consensus, aiming to the provision of quantifiable "tangible goals" for sustainable development.
   - **Improving international cooperation and development aid:** As outlined in the review of Chapter 33 of Agenda 21, future agreements concerning the financing effort for sustainable development should be centered on measurable and time-bound targets.
   - **Reform of international financial institutions:** As discussed in Chapters 33 and 38 of Agenda 21, sustainable development parameters must be better incorporated into the existing international financial institutions.
   - **National, local, and regional governance:** These sustainable development strategies with different scales should be revived and refreshed with full engagement and support from business and all parts of civil society.
   - **International court for the environment:** Environmental problems extend across international boundaries and should be governed globally.

1.2 SUSTAINABILITY IN THE CONTEXT OF SWM

1.2.1 The Possible Conflicts in Achieving the Sustainability Objectives

Achieving sustainability goals involves balancing social, economic, and environmental perspectives constrained by environmental limits over an inter- and intra-generational timeframe, and possible conflicts of objectives related to the three pillars of sustainability would be inevitable. It is necessary to acknowledge and deal with these conflicting objectives across domain boundaries in the diverse spectrum of projects with system thinking. The current waste management industry, which sometimes allows pure commercial opportunism to capitalize promptly on a perceived waste management market, has not completely transformed to embrace or even address sustainability objectives. Actions such as tipping fees, waste stream availability, waste management markets, cost–benefit analyses, competing technologies, longer-term projections, and cross linkages with other industries in relation to supply chain management may be required to aid new systems engineering techniques.

1.2.2 The Possible Sustainability Indicators

In the context of SWM, the concept of sustainability applies to the whole SWM industry sectors, process technologies, and individual process plants. In assessing sustainability performance from storage and collection, to routing and shipping, to separation and treatment, and to final disposal, a system boundary should be well defined. Besides, suitable sustainability indicators to quantify the performance and monitor the progress related to economic, environmental, and social perspectives may be selected for a holistic assessment up front. The perspectives discussed in section 1.1.2 could provide a rational basis to develop appropriate scenarios in SWM. Several key indicators may be considered as options to support a sustainability assessment (Brennan, 2013).

1. **Environmental indicators**
   - **Global-warming potential:** Global-warming potential (GWP) is related to climate change impact and is a relative measure of heat trapped in the atmosphere by greenhouse gases. The GWP value compares the amount of heat trapped by a greenhouse gas to that of carbon dioxide, which has a GWP standard of 1. For example, the GWP of methane is 72 within a 20-year time frame, which means that if the same mass of methane and carbon dioxide were introduced into the atmosphere, that amount of methane will trap 72 times more heat than the carbon dioxide over the next 20 years. The combustion of solid waste may lead to the emission of carbon dioxide and other greenhouse gases.
   - **Ozone layer depletion:** The stratospheric ozone layer forms a thin shield that acts as a sunscreen in the upper atmosphere, protecting life on the surface of Earth from the sun's ultraviolet (UV) rays. Depletion of the ozone layer due to the presence of compounds that contain chlorine and bromine molecules, such as methyl chloroform, halons, and chlorofluorocarbons (CFCs), results in increased UV radiation reaching the Earth's surface, which leads to detrimental health effects such as skin cancer, cataracts, and immune suppression. The final disposal of refrigerant (CFC) at landfills may lead to the impact of stratospheric ozone layer depletion.
   - **Photochemical smog:** Both nitrogen oxides and volatile organic compounds are precursors of photochemical smog in urban regions. High concentrations of nitrogen oxides and volatile organic compounds are associated with industrialization and transportation through fossil fuel combustion. Waste shipping may result in emissions and lead to the generation of photochemical smog.
   - **Human and ecotoxicity:** Human and ecotoxicity indicators are related to public health and risk assessment, exemplified by the toxicity impact on human health from the heavy metal content of organic waste. Air emissions from waste incineration facilities could result in such impacts.
   - **Resources conservation potential:** Separate collection of recyclables from municipal solid waste streams may have greater resources conservation potential.

2. **Economic indicators**
   - **Value-added by-product:** The opportunities of value-added utilization of by-products may be a legitimate sustainability indicator. In waste management, value can be derived at every stage of the chain during collection, shipping, recycling, treatment, and disposal processes. Recyclables, waste heat recovered from waste combustion, compost, as well as the reuse of other residuals may be deemed as value-added by-products.
   - **Contribution to green GDP:** The green GDP is an index of economic growth with the essential correction of environmental consequences of the GDP. Green GDP monetizes the loss of biodiversity and environmental quality and accounts for costs caused by climate change. Environmental costs and benefits of waste management factored into conventional GDP of a country may contribute to the correction of environmental consequences of economic growth.
   - **Environmental costs and benefits:** In CBA of SWM projects, environmental costs and benefits related to waste management may become a set of standalone indicators. CBA is a technique that compares the monetary value of benefits against the monetary value of costs in a series of alternatives to evaluate and prioritize management options. For example, environmental groups in the United States often assert that recycling was doubling energy consumption and pollution while costing taxpayers more money than the potential benefits from value-added by-products.
   - **Environmental liability:** The environmental liability coverage for possible failure of waste management operation tailored to different waste management projects may be deemed as an indicator of sustainability of a waste management project.
3. **Social indicators**
   - **Stakeholder identification and participation:** Stakeholder identification with some analysis techniques is particularly relevant when choosing stakeholders to help waste management agencies organize a participation list. Appropriate forms or channels of participation such as minority group identification in a region would certainly improve the social sustainability.
   - **Income distribution or redistribution through policy instruments:** Income distribution or redistribution measures driven by some policy instruments in SWM projects may be used as an indicator of societal well-being. The distribution or redistribution of compensation or fair fund due to pollution impact caused by waste treatment facilities is a salient example.

1.3 THE FRAMEWORK FOR SUSTAINABILITY ASSESSMENT

The National Research Council in the United States laid out a framework for sustainability assessment structured from the formulation of a problem through achievement of outcomes that warrant a multiagency approach (CSLFG/STSP/PGA/NRC, 2013):

Phase I: Preparation and Planning

- **Frame the problem:** A thorough understanding of the problem is required in all aspects, including environmental resources connections, societal connections, and economic connections. The focus is to determine baseline information, key drivers, metrics, and goals.
- **Identify and enlist stakeholders:** Relevant agency linkages and nonagency stakeholders to serve on the project team must be identified and contacted.
- **Develop a project management plan:** Roles, responsibilities, and accountability of each member must be delineated to create a business plan for project design, implementation, and operation.

Phase II: Design and Implementation

- **Set project goals:** The project team members should formalize the goals together with essential inputs from all stakeholders and relevant members. Evaluation metrics in terms of short-term and long-term outcomes must be outlined in this step.
- **Design an action plan:** The team members should develop a comprehensive plan to elucidate the approaches, strategies, and actions to meet the prescribed goals of the project.
- **Implement the action plan:** At this stage, selecting a boundary organization that bridges scientific and technical experts with policy makers and stakeholders is deemed critical.

Phase III: Evaluation and Adaptation

- **Realize short-term outcomes:** Short-term outcomes that occur on the scale of a year to a few years need to be assessed relative to the baseline information collected in the first phase.
- **Assess and evaluate outcomes:** The knowledge and experience gained is applied to modify problem formulation and adjust approaches, methods, and strategies.

Phase IV: Long-term Outcomes

- **Achieve long-term outcomes:** Short-term outcomes that occur on the scale of a few years or more may be close to the project goals to be achieved. The evaluation plan generated in the second phase may be instrumental to judge if short-term and long-term goals are met.

1.4 THE STRUCTURE OF THIS BOOK

The interactions between human activity and the environment are complicated and often difficult to quantify. In many situations, judging where the optimal balance should lie among environmental protection, social well-being, economic growth, and technological progress is difficult. Decision frameworks refer to principles, processes, and practices to proceed from information and desires to choices that inform actions and outcomes (Lockie and Rockloff, 2005). Decision frameworks may facilitate and

enhance decision making by providing conceptual structures and principles for integrating all sustainability dimensions of decisions (CSLFG/STSP/PGA/NRC, 2013). Development of a decision framework to strengthen sustainability linkages is a challenging task. While decision frameworks vary in purpose, common elements include (CSLFG/STSP/PGA/NRC, 2013) the following:

- problem identification and formulation;
- identification of clear goals;
- illumination of key questions that help the decision maker scope problems and management options;
- processes for knowledge-building and application of appropriate analytical tools to assess actions, options, trade-offs, risks, and uncertainties;
- connection of authorities tasked with making decisions to outcomes associated with those decisions.

Because the system thinking of sustainable development has broad international consensus, this book aims to promote a systems engineering approach for SWM and provide useful sources of advice and information in support of sustainable SWM. The book is thus intended to be used in conjunction with existing literature and other relevant guidance, primarily by academic researchers, policy makers, and waste managers in public and private sectors. It also aims to advance interdisciplinary research of policy and technology relevant to SWM issues interrelated to climate change, land use, economic growth, environmental pollution, industrial ecology, population dynamics, and the interactions among these issues.

This book proposes a systematic decision framework consisting of parallel, interlinked, and complementary processes through science-based analyses with various peripheral subtopics, which is organized within the general perspectives of sustainability for SWM. A comprehensive bibliography is provided at the end of each chapter, and case studies are used to illustrate and demonstrate the processes of sustainability assessment and environmental management. This system-based approach is reflected in the structure of the five parts as follows:

Part I: Fundamental Background: The basic concepts of sustainability science are highlighted and more detailed information is provided on technology matrix and other resources of legal and institutional concerns where social and economic relevance may be interconnected. The following chapters lead to the holistic discussion of environmental risk assessment and management of risk.

- Introduction (Chapter 1)
- Technology matrix for SWM (Chapter 2)
- The social and economic aspects of SWM (Chapter 3)
- The legal and institutional aspects of SWM (Chapter 4)
- A framework for environmental risk assessment and management (Chapter 5)

Part II: Principles of Systems Engineering: The use of formal systems engineering principles including top-down and bottom-up approaches is encouraged to evaluate SWM alternatives. The following chapters are organized to illuminate the internal linkages among global changes, sustainability, and adaptive management strategies and to introduce systems engineering principles. While such a system-based approach related to the integrated SWM should be the norm, risk assessments may sometimes be applied usefully to aid in the decision-making if uncertainties come to bother the choice of adaptive management strategies.

- Linkages among global change, sustainability, and adaptive management strategies (Chapter 6)
- Systems engineering principles and decision-making (Chapter 7)
- Systems engineering tools for evaluating the significance of alternatives (Chapter 8)

Part III: Industrial Ecology and Integrated Solid Waste Management Strategies: Industrial symbiosis with a particular focus on material and energy exchange in natural ecosystem is the foundation of industrial ecology, which includes the study of material and energy flows through ecoindustrial parks in human society. Sustainable SWM is intimately tied to industrial ecology in which life cycle impact assessments of a product and appraisals of SWM processes over or beyond life cycle can be carried out in a more sustainable way. The processes covered in the following chapters command more specific requirements with respect to life cycle concept combined with risk assessment not covered by the general guidelines of Parts I and II.

- Principles of industrial symbiosis and industrial ecology in support of municipal utility parks (Chapter 9)
- Evaluating the significance of life cycle assessment for SWM (Chapter 10)
- Options appraisal and decision-making based on streamlined life cycle assessment (Chapter 11)
- SWM under a carbon-regulated environment (Chapter 12)

Part IV: Integrated Systems Planning, Design, and Management: Considering connections across resource areas and fostering linkages across agencies requires a unique means of sustainability assessment. When coping with complex sustainability issues such as SWM, which is complicated by the separated and dispersed authorities resulting from the basic legal framework, advances in environmental informatics and system analysis may provide a framework for valuable sustainability assessment.

- Multiobjective decision-making framework for SWM in a carbon-regulated environment (Chapter 13)
- Integrated forecasting and optimization modeling for planning regional material recovery facilities in an SWM system (Chapter 14)
- Optimal waste collection and vehicle routing strategies (Chapter 15)

- Multiattribute decision-making framework (Chapter 16)
- Multiobjective decision-making framework for balancing waste incineration and recycling (Chapter 17)
- Environmental informatics in support of SWM (Chapter 18)

Part V: Uncertainty Analyses and Future Perspectives: Risk analysis that fails to account for measurement uncertainties may produce misleading and sometimes dangerous results. Quantitative uncertainty analyses might be useful in systematically evaluating the possible or plausible changes in decision analysis outcomes due to changes in measurement accuracy, sources of data, communication, and social behavior.

- Evaluating the significance of uncertainty with random phenomenon and game theory for SWM in decision-making (Chapter 19)
- Considering linguistic uncertainty related to institutional settings and social behavior by fuzzy multiattribute analysis for SWM in decision-making (Chapter 20)
- Considering linguistic uncertainty related to institutional settings and technological implications by fuzzy multiattribute analysis for SWM in decision-making (Chapter 21)
- Assessing linguistic uncertainty by fuzzy multiobjective programming for SWM in decision-making (Chapter 22)
- Formalizing grey uncertainty by interval programming for SWM in decision-making (Chapter 23)
- Future perspectives (Chapter 24)

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