Introduction

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INTRODUCTION

This book offers an overview of a project where a number of leading personalities in the research and development of the methodology in sustainability field agreed to join forces in the development of a comprehensive edited publication covering the major aspects and issues of assessing and measuring the environmental impact and sustainability. "Sustainability" is an issue that has attracted a lot of attention from researchers and, more recently, from policy-makers. A quick search on September 14, 2014, in SCOPUS (2014) showed 21,865 publications containing this word. However, looking for both "sustainability" and "assessment" in the title resulted in only 1,256 papers, and the search for "sustainability" and "measurement" revealed even less—just 76 papers—dealing with those issues. This means that from the overall pool of sustainability-related publications, only 5% deal with "sustainability and assessment" and only 0.3% deal with "sustainability and measurement."

That simple illustration has highlighted the importance of a project dealing with not solely "sustainability" but rather "sustainability" and "assessment" and "measurement," with the latter emphasizing the need for quantitative characterization of the issues being considered.

A number of relevant questions and issues have been formulated in relation to sustainability measurement and assessment. They include the following:

1. How do we define sustainability?
2. How do we assess sustainability?
3. How do we measure sustainability?
4. How do we set up a policy for sustainability?
5. How can Fisher Information be applied to measuring and assessing sustainability issues?
6. System Analysis Approach to sustainability
7. The Environmental Performance Strategy Map
8. Sustainable Process Index (SPI)
9. Environmental/Green House Gas Emissions (GHGE)/nitrogen/water footprints
10. Life-cycle sustainability aspects
11. What is a decision point in sustainability analysis?
12. How do we reach sustainable design?

A number of leading researchers in the field have been approached and the majority enthusiastically accepted the challenge to find, discuss, and present answers and potential solutions to these issues. The main topics used for developing the answers from various viewpoints have been compiled in this edited book. They (not solely) include:

- *Systems analysis approach to sustainability*
- The Application of Fisher Information to Environmental and Engineering Problems
- SPI
- How to reach a decision point in sustainability analyses
- Overview of environmental footprints
- Nitrogen footprint and the nexus between carbon and nitrogen footprints
- The analysis of the water footprint (WF) of industry
- Life-cycle sustainability aspects of microalgae biofuels
- Methods and tools for sustainable process design
- The built environment and embodied energy
- The Environmental Performance Strategy Map: An integrated life-cycle analysis (LCA) approach to support the strategic decision-making process
- Sustainable design through process integration
- Supply and demand planning and management tools driving development toward low carbon emissions
- Setting a policy for sustainability: the importance of measurement
- Sustainability assessment of buildings, communities, and cities.

The book has been structured into several main parts:

1. The introduction deals with suitability definitions, systems approach to sustainability, and ways to express and measure sustainability (Chapters 1–3).
2. The second part is devoted to an important part of sustainability assessment and quantification of environmental impacts—footprints. This topic has had turbulent development and the works studying and developing various footprints have been escalating quickly (Chapters 4–7).
3. The third part presents contributions to sustainable design, planning, and management. There are various aspects including planning and strategic tools, the design of sustainable processes, supply chains, which constitute an important (but not always sufficiently studied and optimized) part, and also management tools (Chapters 8–13).
4. The final part deals with policies steering industrial and economic development toward sustainability (Chapter 14) and a mostly chemical and mechanical engineering view of this problem regarding sustainability assessment of buildings, communities, and cities (Chapter 15). Communities and cities are important end-users of the several engineering disciplines and production processes.

A short overview of those main parts to provide an executive summary is presented.

SUITABILITY DEFINITIONS, SYSTEMS APPROACH TO SUSTAINABILITY, AND WAYS TO EXPRESS AND MEASURE SUSTAINABILITY

The first chapter, authored by Urmila Diwekar, deals with the title topic itself—Engineering Sustainability. The chapter provides the vision that sustainability analysis is, by definition, multidisciplinary. Further in the chapter, engineering sustainability is presented by using various systems analysis approaches from different disciplines. A hierarchical consideration of sustainability at several system levels is offered, starting with green manufacturing, extending to industrial networks, and then extending to the ecosystem level. All systems considered at those levels are complex and extend boundaries of current analysis frameworks. There have been uncertainties at every stage of analysis. To deal with the uncertainties in a systematic way has been a strong requirement. The presented analysis applies optimization and social science approaches.

What should be noted is one of most widely accepted definitions of sustainability or sustainable development that is attributed to the World Commission on Environment and Development (1987). This concept of sustainability, since the publication of the Brundtland report known as Our Common Future (1987), has been widely used as a rationale to focus on the long-term effects of anthropogenic activities on nature. That Commission stated in their final report that "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs." There have been several other definitions of sustainability; however, this was one of the first and it still has its importance.

The Brundtland Commission's definition (1987) of sustainability originated from the concerns that current trends in population and economic developments are not sustainable. Already at the beginning of this century it has been obvious that a number of adverse environmental impacts are threatening the global ecosystem (Cabezas, 2013). Impacts that are considered include the following: global climate change; degradation of air, water, and land; depletion of natural resources, including freshwater minerals; and loss of agricultural land because of deforestation, soil erosion, and urbanization.

This first chapter further extends the presentation of the approach to engineering systems analysis for achieving sustainability. It has been based on the premise that sustainable manufacturing extends the boundaries of traditional design and modeling frameworks to include multiple objectives and should be started as early as possible. Uncertainties increase as the modeling is expanded. Industrial ecology broadens this framework to industrial networks level and accounting for time-dependent uncertainties becomes necessary. The author of the first chapter expressed strong opinion that the adaptive management is a key to sustainability at this level. Mental models for uncertainty analysis are considered potentially useful for solving tasks. Sustainability goes beyond industrial ecology and the boundary extends to our planet. The time scale for decision-making extends significantly and forecasting the consequences from proposed decisions is very important. As a result, the main sustainability challenges, such as modeling phenomena, modeling uncertainties, time-dependent decision-making, defining objectives, and forecasting, are still waiting for adequate answers.

The second chapter was authored by Alejandra González-Mejía, Leisha Vance, Tarsha Eason, and Heriberto Cabezas. It is based on the notion that assessing sustainability in human and natural systems is often hampered by complex dynamics, multiplicity of time scales, and inherent linkages among the observable properties. This has obviously been the case and makes sustainability assessment a complicated issue.

Although many indicators have been identified as useful in classifying and indicating trends of movement toward and away from sustainability, evaluating changes in system behavior requires simultaneously monitoring multiple variables over time. For this reason, great value can be found in methods that can capture the dynamics of multidimensional systems. Fisher Information (Fisher, 1922) offers a tool that can combine multiple variables into an index adequately representing its components that can be monitored over time to assess changes in the dynamic behavior of systems. The concept of Fisher Information has demonstrated promise in capturing dynamic order and detecting regime shifts in models and real systems, but challenges in handling data quality and interpreting results can limit its application. Overall, the second chapter summarizes ongoing activities that enhance the effectiveness of the approach and extends them to develop practical mechanisms for monitoring and managing highly complex and integrated systems toward sustainability.

The authors have demonstrated that the initial development and application of the approach involved using Fisher Information can derive fundamental equations of physics, thermodynamics, and population genetics (Frieden, 1998,) which have been further developed, including their own contributions. Fisher Information was later proposed as a sustainability metric by Cabezas and Fath (2002) and has been used to study changes in dynamic order in model systems, such as multispecies food webs (Pawlowski and Cabezas, 2008), pseudo-economies (Cabezas et al., 2005), and real ecosystems such as the Bering Strait, the western African savannah, the US Florida pine-oak, and global climate changes (Mayer et al., 2007).

The approaches described in Chapter 2 emphasize a number of points in relation to Fisher Information analysis:

- The selection of variables is critical for ensuring relevant analyses because inadequate representation of the system leads to results that are not of much use for monitoring and management.

- Natural systems often exhibit periodic behavior or cycles, by its own features or when interacting with human populations. Periodic behavior (e.g., wastewater treatment model) and scale of study impact the characterization of system dynamics and introduce uncertainty. However, Fischer Information can be used to distinguish patterns even when cycle periods are unknown.
- Data quality is a great challenge when reducing the uncertainties attributable to detection errors. In this regard, an analytical approach and mechanisms have been developed and demonstrated by the authors of Chapter 2 to help manage such difficulties.
- Interpretation of the results of Fischer Information analyses has been challenging and may have inhibited broader use of the index. Several approaches have been presented in this chapter that can increase the clarity and enhance the identification of important findings.

It can be concluded that Chapter 2 demonstrates the utility of Fischer Information as an effective tool for monitoring systems, assessing dynamic change, and informing actions to help guide complex human and natural systems toward sustainability. The authors found Fisher Information used in a number of studies assessing changes in city structure (Eason and Garmenstani, 2012), characterizing political instability in nation states (Karunanithi et al., 2011), and studying the dynamics of lead concentration levels in conjunction with regulatory actions (Gonzalez-Mejia et al., 2012). They stated that their future work should cover the following:

- Examining the usefulness of the continuous form method in capturing regime dynamics
- Using multivariate techniques to determine the drivers of system behavior
- Investigating the utility of the index studying the resilience of various system types (e.g., ecological, social, and supply chain systems)
- Using Fischer Information to assess spatial dynamics
- Further exploring signals in Fisher Information as a leading indicator in critical transitions.

Chapter 2 is also equipped with comprehensive annexes providing more detailed explanations of Fisher Information application.

Chapter 3 introduces a way to integrate sustainability assessment into engineering design on the same footing as economic considerations. Michael Narodoslawsky and his team introduced the SPI, which addresses this need and provides a comprehensive evaluation of sustainability from the viewpoint of ecology. It is based on the concept of strong sustainability (Narodoslawsky and Krotscheck 1995). It can be used even when only mass and energy balances are known to an engineer, as is usually the case during early stages of process design. The SPI calculates an ecological footprint over the whole life cycle of a product or service provided by technology. The main part of the evaluation is the calculation of the area necessary to bring to life the provision of the service or product