LCA Compendium – The Complete World of Life Cycle Assessment

Series Editors: Walter Klöpffer · Mary Ann Curran

Matthias Finkbeiner *Editor*

Special Types of Life Cycle Assessment

Springer

LCA Compendium – The Complete World of Life Cycle Assessment

Series editors

Walter Klöpffer, LCA Consult & Review, Frankfurt am Main, Germany
Mary Ann Curran, BAMAC, Ltd., LCA & Sustainability Consultant, Rock Hill, SC, USA

Aims and Scope

Life Cycle Assessment (LCA) has become the recognized instrument to assess the ecological burdens and human health impacts connected with the complete life cycle (creation, use, end-of-life) of products, processes and activities, enabling the assessor to model the entire system from which products are derived or in which processes and activities operate. Due to the steady, world-wide growth of the field of LCA, the wealth of information produced in journals, reports, books and electronic media has made it difficult for readers to stay abreast of activity and recent developments in the field. This led to the realization of the need for a comprehensive and authoritative publication.

LCA Compendium – The Complete World of Life Cycle Assessment will discuss the main drivers in LCA (SETAC, UNEP/SETAC Life Cycle Initiative, etc.), the strengths and limitations of LCA, the LCA phases as defined by ISO standards, specific applications of LCA, Life Cycle Management (LCM) and Life Cycle Sustainability Assessment (LCSA). Further volumes, which are closely related to these themes will cover examples of exemplary LCA studies ordered according to the importance of the fields of application. They will also present new insights and new developments and will keep the whole work current. The aim of the series is to provide a well-structured treatise of the field of LCA to give orientation and guidance through detailed descriptions on all steps necessary to conduct an LCA study according to the state of the art and in full agreement with the standards.

LCA Compendium – The Complete World of Life Cycle Assessment anticipates publishing volumes on the following themes:

- Background and Future Prospects in Life Cycle Assessment (published in March 2014)
- Goal and Scope Definition in Life Cycle Assessment (published in August 2016)
- Life Cycle Inventory Analysis (LCI)
- Life Cycle Impact Assessment (LCIA) (published in March 2015)
- Interpretation, Critical Review and Reporting in Life Cycle Assessment
- Applications of Life Cycle Assessment
- Special Types of Life Cycle Assessment (published in July 2016)
- Life Cycle Management (LCM) (published in August 2015)
- Life Cycle Sustainability Assessment (LCSA)
- Life Cycle Assessment Worldwide

More information about this series at http://www.springer.com/series/11776

Matthias Finkbeiner
Editor

Special Types of Life Cycle Assessment

Springer

Editor
Matthias Finkbeiner
Chair of Sustainable Engineering
Institute of Environmental Technology
Technische Universität Berlin
Berlin, Germany

ISSN 2214-3505 ISSN 2214-3513 (electronic)
LCA Compendium – The Complete World of Life Cycle Assessment
ISBN 978-94-017-7608-0 ISBN 978-94-017-7610-3 (eBook)
DOI 10.1007/978-94-017-7610-3

Library of Congress Control Number: 2016947060

Printed on acid-free paper

This Springer imprint is published by Springer Nature
The registered company is Springer Science+Business Media B.V. Dordrecht

Preface

The title of this volume of the *LCA Compendium* book series reads *Special Types of Life Cycle Assessment*. This may raise immediate questions about what is actually meant by special types of LCA and which types of LCA are supposed to be covered by this term. Let me give you some background first, before I try to answer this question more concretely than the usual LCA experts' answer: "…it depends…."

When the *LCA Compendium* was conceived and as a follow-up to the introductory volume *Background and Future Prospects in Life Cycle Assessment* (published 2014), the series editors, Walter Klöpffer and Mary Ann Curran, planned an overall structure of individual topics/volumes that could be clustered into two main categories:

1. Volumes that basically address the classical four phases of LCA as defined by the ISO:

   Goal and scope definition (published 2016)
   Inventory analysis
   Impact assessment (published 2015)
   Interpretation

2. Volumes that focus on applications of LCA that go beyond the environment as the only dimension and that include new developments and approaches:

   – LCA application
   – Special types of LCA (published 2016)
   – Life cycle management (published 2015)
   – Life cycle sustainability assessment

While the allocation of specific topics and methods is rather straightforward for the first category, it gets a bit trickier for the latter. When I started to populate the outline of the present volume *Special Types of Life Cycle Assessment*, I tried to cover basically some main developments of "new" approaches that go beyond or were built on the basis of classical, product-related, attributional, process-based

LCA. Several of them were driven by the trend toward – mainly communication or "footprint"-driven – simplification; others were the result of the trend toward sustainability-driven sophistication.

Following this approach, synergies and overlaps with other volumes of the *LCA Compendium* series became obvious. While life cycle sustainability assessment (LCSA) and the associated methods of life cycle costing (LCC) and social LCA (SLCA) would clearly fall under this generic working definition of special types of LCA, they are actually covered as a separate *LCA Compendium* volume on LCSA edited by Alessandra Zamagni, Tomas Ekvall, and Michael Martin. As a consequence, LCC, SLCA, and LCSA are not included here.

Other topics like water footprint or resource efficiency are partly addressed by the volume on impact assessment edited by Michael Hauschild and Mark Huijbregts. While they are discussed there from the viewpoint of an individual impact category within LCA, they are still included in this volume, but more from the perspective of a stand-alone approach.

In that sense, all the topics covered in this volume fall under the broad definition given above, but they obviously do not provide a complete and exclusive coverage of it. This volume contains a rather interesting potpourri of topics from carbon footprinting, water footprinting, eco-efficiency assessment, resource efficiency assessment, input-output (IO) and hybrid LCA, and material flow analysis (MFA) to organizational LCA, which are not covered by the other volumes.

It is evident that these topics cannot comprehensively be covered in a single volume, and besides the development goes on. Further volumes, which are closely related to these themes, will present new insights and new developments and will keep the whole work current.

Because this *Special Types of Life Cycle Assessment* volume is therefore indeed special, we decided to go into a bit more detail on recent trends toward special types of LCA. This is part of Chap. 1 "Introducing Special Types of Life Cycle Assessment," which also provides a detailed overview of the contents, the authors, and the individual chapters of this volume.

Nora Roberts wrote once: "If something isn't special, then it's ordinary." In that sense, I sincerely hope that this volume lives up to the "special" expectations expressed by its title and that – most importantly of all – you enjoy reading it.

Berlin, Germany Matthias Finkbeiner
1 February 2016

Acknowledgments

It is rewarding to see this volume finally published after having worked on it for about 2 years. This would have not been possible without the outstanding contributions and tremendous efforts of many colleagues.

First and foremost, I have to acknowledge all the **authors** of this volume. I am grateful that these leading scholars for the different topics committed to provide a contribution for this book. It was a great pleasure to experience the competence, motivation, and engagement of all of you – despite the different challenges involved. Those of you who delivered your contributions early in the process had to patiently wait for publication, while others had to bear with me for pushing them to complete their chapters at the very end of the process. Atsushi Inaba has to be acknowledged in particular as he was not just the main author, but basically the editor of Chap. 2 “Carbon Footprint of Products.” He brought together a team of nine coauthors from various organizations in different countries, who contributed individual sections to this comprehensive overview on the development, application, and impact of CFP in different parts of the world.

Next to the authors, the **referees** (Jeroen Guinée, Yasunari Matsuno, Llorenç Milà i Canals, Shinichiro Nakamura, Sangwon Suh) deserve sincere thanks for sharing their knowledge and experience. The extensive and valuable feedback provided by them helped the authors to improve their chapters in many respects.

The comments of the referees were complemented by the final revision of the **series editors** of the *LCA Compendium*, Walter Klöpffer and Mary Ann Curran. They handled the reviewed articles out of their long experience and contributed valuable suggestions and final advice. I personally like to thank Walter and Mary Ann for their trust in me as editor of this volume.

Last, but by no means least, I have to express my cordial gratitude to Almut B. Heinrich, the **managing editor** of the *LCA Compendium*, who supported me in a really substantial way by spending plenty of hours working with authors and referees, editing the articles, and controlling the production process.

I particularly like to thank my sustainable engineering group at Technische Universität Berlin for all their support. Their commitment and professionalism allows me to do such extra projects on top of our regular duties.

Finally, a sincere thanks is given to my family for their courtesy and patience.

Contents

Contributors

Vanessa Bach Chair of Sustainable Engineering – Institute of Environmental Technology, Technische Universität Berlin, Berlin, Germany

Markus Berger Chair of Sustainable Engineering – Institute of Environmental Technology, Technische Universität Berlin, Berlin, Germany

Sylvain Chevassus French Ministry for Environnent, Energy and Sea (MEEM), Paris, France

Tom Cumberlege The Carbon Trust, London, UK

Matthias Finkbeiner Chair of Sustainable Engineering – Institute of Environmental Technology, Technische Universität Berlin, Berlin, Germany

Eunah Hong Korea Environmental Industry & Technology Institute (KEITI), Seoul, Republic of Korea

Atsushi Inaba Department of Environmental and Energy Chemistry, Kogakuin University, Tokyo, Japan

Akira Kataoka Japan Environmental Association for Industry (JEMAI), Tokyo, Japan

David Laner Institute for Water Quality, Resource and Waste Management, Vienna University of Technology, Vienna, Austria

Christian Doppler Laboratory for Anthropogenic Resources, Vienna University of Technology, Vienna, Austria

Pongvipa Lohsomboon Thailand Greenhouse Gas Management Organization (TGO), Bangkok, Thailand

Julia Martínez-Blanco Chair of Sustainable Engineering – Institute of Environmental Technology, Technische Universität Berlin, Berlin, Germany

Corinne Mercadie EMC Distribution Groupe Casino, Vitry sur Seine, France

Masaharu Motoshita Research Institute of Science for Safety and Sustainability, National Institute of Advanced Industrial Science and Technology (AIST), Tsukuba, Ibaragi, Japan

Thumrongrut Mungcharoen National Science & Technology Development Agency and Faculty of Engineering, Kasetsart University, Bangkok, Thailand

Shinichiro Nakamura Faculty of Political Science and Economics, Waseda University, Tokyo, Japan

Keisuke Nansai National Institute for Environmental Studies, Center for Material Cycles and Waste Management Research, Ibaraki, Japan

Stephan Pfister Institute of Environmental Engineering (IfU), ETH Zurich, Zurich, Switzerland

Klaus Radunsky Umweltbundesamt GmbH, Vienna, Austria

Helmut Rechberger Institute for Water Quality, Resource and Waste Management, Vienna University of Technology, Vienna, Austria

Peter Saling Sustainability Strategy, BASF SE, Ludwigshafen, Germany

Laura Schneider Chair of Sustainable Engineering – Institute of Environmental Technology, Technische Universität Berlin, Berlin, Germany

Acronyms

AADP	Anthropogenic stock extended abiotic depletion potential
ACFN	Asia Carbon Footprint Network
ADP	Abiotic depletion potential
AHG	Ad hoc group
AoP	Area of protection
AOXs	Adsorbable organic halogens
AP	Acidification potential
APC	Air pollution control
ASUE	Arbeitsgemeinschaft für sparsamen und umweltfreundlichen Energieverbrauch e.V. Germany: Comparison of heating costs in new developments, 2009
AWS	Alliance for Water Stewardship
BOD	Biological oxygen demand
BSI	British Standards Institution
CBO	Carbon business office
CDP	Carbon disclosure project
CED	Cumulative energy demand
CFs	Characterization factors
CFCs	Chlorofluorocarbons
CFL	Compact fluorescent lamp
CFP	Carbon footprint of products
CGE	Computable general equilibrium
CML-IA	CML impact assessment
COD	Chemical oxygen demand
CSI	Cement sustainability initiative
CSR	Corporate social responsibility
CTA	Ratio of water use to consumption availability
CV	Coefficient of variation
DALY	Disability-adjusted life year
DMC	Domestic material consumption

DMI	Domestic material input
DTA	Demand to availability
ECF	Elemental chlorine-free
ECM	Eco-care matrix
EDP	Ecosystem damage potential
EEA	Eco-efficiency analysis
EEIO	Environmentally extended IO
EF	GHG emission factor
EIA	Environmental impact assessment
EMAS	Eco-management and audit scheme
EMC	Environmentally weighted material consumption
EMS	Environmental management system
EoL	End of life
EPDs	Environmental product declarations
EPR	Extended producer responsibility
ESP	Economic resource scarcity potential
EWR	Environmental water requirement
EWS	European Water Stewardship
EXIOPOL	Externality data and input-output tools for policy analysis
GDP	Gross domestic product
GE	General equilibrium model
GefStoffV	Hazardous Substances Regulation Act
GHGs	Greenhouse gases
GLS	General lighting standard
GRI	Global reporting initiative
GWP	Global warming potential
HAL	Halogen lamp
HCl	Hydrogen chloride
HCs	Hydrocarbons
HF	Hydrogen fluoride
HMs	Heavy metals
ICP	International comparison program
IO-LCA	Input-output and hybrid LCA
IOT	IO table
IPCC	Intergovernmental Panel on Climate Change
ISIC	International Standard Industrial Classification of All Economic Activities
ISO	International Organization for Standardization
LCA	Life cycle assessment
LCC	Life cycle costing
LCIA	Life cycle impact assessment
LCSA	Life cycle sustainability assessment
LSFs	Life support functions
MFA	Material flow analysis

MIOT	Monetary IO table
MRIO	Multiregional input-output table
MSW	Municipal solid waste
MSY	Maximum sustainable yield
NACE codes	Nomenclature Générale des Activités Economiques dans les Communautés Européennes
NPP	Net primary production
NPV	Net present value
NSF	National Sanitation Foundation
OBIA	Overall business impact assessment
ODP	Ozone depletion potential
OEF	Organizational environmental footprint
OEFSRs	Organization environmental footprint sector rules
OLCA	Organizational LCA
OSHA	Occupational safety and health act
OSR	Old scrap ratio
PAS	Publicly available specification
PCRs	Product category rules/environmental product declarations
PDF	Potentially disappeared fraction
PEF	Product environmental footprint
PEF guide	Organization environmental footprint guide (PEF guide)
PEMFC	Proton exchange membrane fuel cell
PGMs	Platinum group metals
PIOT	Physical IOT
PLCA	Process-based LCA
POCP	Photochemical oxidation creation potential
PPP	Purchasing power parity
PUR	Polyurethane
RDF	Residue-derived fuel
REEs	Rare earth elements
ROW	Rest of the world
SCP	Sustainable consumption and production
SD	Sustainable development
SE	Statistical entropy
SEA	Statistical entropy analysis
SEEBALANCE	Social eco-efficiency analysis, trade name SEEBALANCE
SETAC	Society of Environmental Toxicology and Chemistry
SFA	Substance flow analysis
SKUs	Stock keeping units
SLCA	Social LCA
SMEs	Small- to medium-sized enterprises
TGO	Thailand Greenhouse Gas Management Organization
TMI	Total material requirement
UNCED	United Nations Conference on Sustainable Development

UNESCAP	United Nations Economic and Social Commission for Asia and the Pacific
UNFCCC	United Nations Framework Convention on Climate Change
USLP	Unilever Sustainable Living Plan
VOCs	Volatile organic compounds
WAVE	Water accounting and vulnerability evaluation
WBCSD	World Business Council for Sustainable Development
WF	Water footprint
WFN	WaterStat database
WIO-MFA	Waste input-output material flow analysis
WRI	World Resources Institute
WSI	Water stress index
WTA	Ratio of water use to water availability
WTO CTE	Committee on Trade and Environment of the World Trade Organization
WULCA	Water use in LCA

Chapter 1
Introducing "Special Types of Life Cycle Assessment"

Matthias Finkbeiner

Abstract Based on the classical methods and standards of life cycle assessment (LCA), there is recently a trend toward the diversification and proliferation of "new" life cycle-based assessment approaches. They are summarized in this volume/book under the heading of *Special Types of Life Cycle Assessment* and include:

- Carbon footprinting
- Water footprinting
- Eco-efficiency assessment
- Resource efficiency assessment
- Input-output (IO) and hybrid LCA
- Material flow analysis (MFA)
- Organizational LCA

The nature and scope of these special types of LCA are rather different. Some represent specific impact categories in the form of seemingly simplified stand-alone footprinting methods; some represent complementary modeling approaches like MFA, IO-LCA, and hybrid LCA; and some represent a broader application context (organizational LCA, OLCA) or a broader sustainability scope of the assessment (resource and eco-efficiency assessment). This volume contains state-of-the-art contributions for each of these special types of LCA by leading experts in the respective field.

Keywords Carbon footprint • CLCA • Consequential LCA • Eco-efficiency assessment • Hybrid LCA • IO-LCA • Input-output LCA • ISO 14040 • ISO 14044 • LCA • LCC • LCSA • Life cycle assessment • Life cycle costing • Life cycle sustainability assessment • Material flow analysis • MFA • OEF • Organizational environmental footprint • Organizational LCA • OLCA • PAS 2050 • PEF • Product environmental footprint • Resource efficiency assessment • SLCA • Social LCA • Water footprint

M. Finkbeiner (✉)
Chair of Sustainable Engineering – Institute of Environmental Technology, Technische Universität Berlin, Office Z1, Strasse des 17. Juni 135, 10623 Berlin, Germany
e-mail: matthias.finkbeiner@tu-berlin.de

M. Finkbeiner (ed.), *Special Types of Life Cycle Assessment*, LCA Compendium – The Complete World of Life Cycle Assessment,
DOI 10.1007/978-94-017-7610-3_1

Acronyms

IO-LCA	Input-output and hybrid LCA
LCC	Life cycle costing
LCSA	Life cycle sustainability assessment
MFA	Material flow analysis
OEF	Organizational environmental footprint
OLCA	Organizational LCA
PEF	Product environmental footprint
SLCA	Social LCA
WBCSD	World Business Council for Sustainable Development
WRI	World Resources Institute

1 Introduction

Life cycle assessment (LCA) is a well-established and widely used environmental management tool. The history and several milestones of its development were comprehensively described in the first volume called *Background and Future Prospects in Life Cycle Assessment* (Klöpffer 2014) of this book series *LCA Compendium – The Complete World of Life Cycle Assessment* (series editors Walter Klöpffer and Mary Ann Curran).

LCA started to boom around 20 years ago. Part of this growth came from increased application and implementation of LCA in both private and public decision-making, which was supported by well-accepted international standards (Finkbeiner et al. 2006; Finkbeiner 2013, 2014b; ISO 14040 2006; ISO 14044 2006). However, a significant additional momentum was generated by the development of "new" approaches built on the basis of classical LCA. This volume acknowledges these special types of LCA by dedicating the whole book to some of the most prominent species of this emerging trend:

- Carbon footprinting (see *Chap*. 2)
- Water footprinting (see *Chap*. 3)
- Eco-efficiency assessment (see *Chap*. 4)
- Resource efficiency assessment (see *Chap*. 5)
- Input-output (IO) and hybrid LCA (see *Chap*. 6)
- Material flow analysis (MFA) (see *Chap*. 7)
- Organizational LCA (see *Chap*. 8)

Life cycle sustainability assessment (LCSA) and the associated methods of life cycle costing (LCC) and social LCA (SLCA) are further important species of special types of LCA. However, there will be a separate volume on LCSA within the *Compendium* book series edited by Alessandra Zamagni, Tomas Ekvall, and Michael Martin, and so LCC, SLCA, and LCSA are not covered here. More recently, the EU Commission proposed methods called Product and Organizational

Environmental Footprint (PEF and OEF, respectively). They are still under development and currently undergo a pilot testing phase. If this process is completed and turns out to be successful, future volumes on special types of LCA may include contributions on PEF and OEF. As of now, the opportunities and threats of PEF and OEF are still under debate (Finkbeiner 2014a; Galatola and Pant 2014; Lehmann et al. 2015).

This introductory *Chap.* 1 describes some of the recent trends toward special types of LCA in Sect. 2. Section 3 contains an overview of the individual chapters of this volume. Section 4 concludes the chapter with a summary and outlook.

2 Recent Trends Toward Special Types of LCA

The LCA community has a fairly long tradition of methodological debates. Discussions about the best impact assessment method, the best allocation procedures for coproducts and end of life, the best database, the best uncertainty and data quality assessment, proper normalization, weighting or not, and many more are daily business for LCA practitioners. As a consequence, the first species of special types of LCA were mainly driven and inspired by methodological issues. IO-LCA (input-output LCA) and also consequential LCA (CLCA), therefore, still refer to LCA, but proposed a different methodological setting. Unfortunately, both of them were originally often oversold as a better alternative or substitute of good old standard LCA, i.e., attributional, process-based LCA in modern terms. Nowadays, it is recognized that they are more complementary than competitive. In real-world application for decision-making, standard LCA is the established tool, while IO-LCA can help as macroeconomic scale-up or screening tool, and consequential LCA can be used to simulate some future scenarios as additional sensitivity analysis.

More recently, special types of LCA were driven by different developments and trends. On the one hand, there is a trend toward – mainly communication-driven – simplification; on the other hand, there is a trend toward sustainability-driven sophistication. On the simplification side, the term "footprint" started to emerge.

Carbon footprinting was a huge driver for the market expansion of simplified "LCA." The carbon footprint discussions led to a huge proliferation of different guidelines and standards including ISO/TS 14067 on carbon footprint of products (ISO/TS 14067 2013), the Greenhouse Gas Protocol Product Life Cycle Accounting and Reporting Standard of the World Business Council for Sustainable Development (WBCSD), and the World Resources Institute (WRI), PAS 2050, and further national guidelines from, e.g., Japan, Korea, the European Union, France, Germany, and New Zealand (Finkbeiner 2009; Finkbeiner et al. 2006).

The second generation of footprint was the *water footprint*. Next to stand-alone methods, such as virtual water, the method of the Water Footprint Network, the Global Water Tool, or the Corporate Water Gauge, many methods were developed in an LCA context (Berger and Finkbeiner 2013). Both the increasing relevance of water footprinting and the diverse methods were the drivers to develop the ISO 14046 as an international water footprint standard (ISO 14046 2014). The footprint trend is not over yet. Nowadays, there are “whatever” footprints for almost everything from nitrogen over biodiversity to bulky organizational environmental footprints.

The sophistication trend goes in the opposite direction. Rather than selecting specific environmental impacts and aspects out of the comprehensive set of impacts to be studied in classical LCA, the underlying methodology is either adapted for other sustainability dimensions like in LCC and SCLA and/or brought into the context of further sustainability dimensions like in resource and eco-efficiency assessments.

A schematic typology of these tools and developments is presented in Fig. 1.1 (Finkbeiner et al. 2010) according to an adapted pyramid of needs from Maslow (1943). While the original pyramid of Maslow has the basic physiological needs like food and water at the bottom, followed by safety needs, love and belonging, and esteem until self-actualization at the very top, the adapted version starts with the basic approach of life cycle thinking, followed by single-issue methods like carbon or water footprinting, LCA, and resource or eco-efficiency assessment up to LCSA at the top of the pyramid (see Fig. 1.1).

The interpretation of the Maslow pyramid of environmental and sustainability assessment should be similar to the original pyramid on human needs. This means that the hierarchy does not imply any ranking of which tool is better than another. It rather addresses different levels of sophistication and therefore can be used to define development paths. If organizations or stakeholders have just started with integrating sustainability considerations into their processes and practices, life cycle thinking is a good starting point. If climate change is the most relevant issue in some parts of the globe and water scarcity in others, it is feasible and pragmatic to start the more quantitative assessments with the respective single-aspect tools. Once this is done, the next step for these organizations is rather obvious, and they can develop more complete and comprehensive environmental assessments in the form of real LCA. Once this level is reached, the other sustainability dimensions can be integrated (Finkbeiner et al. 2010).

In that sense, the two LCA megatrends introduced above – simplification and sophistication – go in different directions, but they are still complementary from an application perspective. The Maslow’s pyramid for life cycle-based environmental and sustainability assessment approaches unites both trends in a common framework. Simplification approaches are good to reduce the entry barrier to start working with quantitative life cycle-based assessment tools, and the sophistication approaches open up new application fields for those organizations which already have implemented LCA.

Last, but not least, a more recent development which could develop a new trend is the application of LCA on the organizational level. This “new member of the LCA family” (Martinez-Blanco et al. 2015a, b, c) takes up ideas and concepts toward product- and organization-related environmental assessment and management tools developed in the 1990s (Finkbeiner et al. 1998). It seems that time has

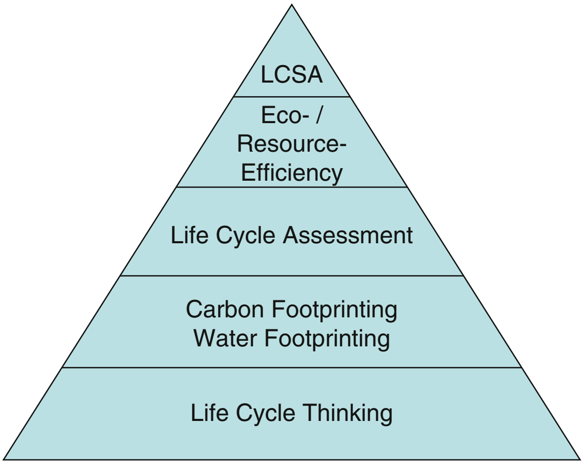

Fig. 1.1 Adaptation of Maslow’s pyramid of human needs for life cycle-based environmental and sustainability assessment approaches (Reproduced from Finkbeiner et al. 2010)

come to expand the traditional product orientation of LCA toward an organizational perspective as the benefits and the potential of the life cycle approach are not limited to an application on products. The publication of ISO/TS 14072 on organizational LCA (ISO/TS 14072 2014) and the guidance document of the UNEP/SETAC Life Cycle Initiative are expected to support a growing application of LCA for organizations (UNEP 2015). Organizational LCA might also be a key catalyst for the application breakthrough of social LCA as most social issues and indicators are typically managed on the organizational level (Martinez-Blanco et al. 2015c).

3 Overview of the Volume

Chapter 2 describes the carbon footprint of products in several regions of the world. For this contribution, Atsushi Inaba from Kogakuin University in Tokyo did an outstanding job by providing an up-to-date status of this topic. He brought together a great team of coauthors representing key actors in this field including Sylvain Chevassus (French Environment Ministry, Paris, France), Tom Cumberlege (The Carbon Trust, London, United Kingdom), Eunah Hong (Korea Environmental Industry and Technology Institute, Seoul, Republic of Korea), Akira Kataoka (Japan Environmental Management Association for Industry, Tokyo, Japan), Pongvipa Lohsomboon (Thailand Greenhouse Gas Management Organization, Bangkok, Thailand), Corinne Mercadie (EMC Distribution Group Casino, Marne-la-Vallée, France), Thumrongrut Mungcharoen (National Science and Technology Development Agency and Kasetsart University, Bangkok, Thailand), and Klaus Radunsky (Umweltbundesamt, Vienna, Austria). The chapter starts with a historic overview of the developments and provides details of the carbon footprint approaches and programs in the UK, France, Japan, Korea, and Thailand.

Chapter 3 focuses on water footprinting and addresses the question of "how to count the drops and assess the impacts." The author team of Markus Berger (Technische Universität Berlin, Germany), Stephan Pfister (ETH Zurich, Switzerland), and Masaharu Motoshita (Agency of Industrial Science and Technology, Tsukuba, Japan) represents leading scholars in the field with complementary competencies. Their contribution starts with a status of water resources and demands from a global and regional perspective followed by a necessary clarification of terminology. A core part is the discussion and comparison of the different water footprint methods, databases, and tools. Lessons learned from water footprint case studies, remaining challenges, and an outlook including the consensus model WULCA complete this chapter.

Chapter 4 broadens the perspective toward eco-efficiency assessment. Peter Saling from BASF SE in Ludwigshafen, Germany, is one of the key actors in this field representing a company that is one of the pioneers and most prominent supporters of the eco-efficiency concept. In this chapter, a general introduction to the concept is followed by an introduction of the so-called sustainability assessment toolbox developed by BASF. This includes the BASF-specific type of eco-efficiency analysis plus adaptions of it like the so-called SEEBALANCE and AgBalance applications. Several case studies and examples are presented in order to demonstrate both the method as such and its application potential.

Chapter 5 addresses multidimensional LCA perspectives in the form of resource efficiency assessment. Laura Schneider and Vanessa Bach from my group at Technische Universität Berlin, Germany, provide a state-of-the-art review of this field. After a proper definition and classification of "resources" in the context of LCA, the current methods for the assessment of abiotic and biotic resource use in LCA are introduced. The shortcomings of the more established topic of abiotic resources with regard to the inherent property of materials, current reserves, and/or annual extraction rates as well as future consequences of resource extraction are discussed. The chapter concludes with an overview of research needs and proposed methodological developments for abiotic resource efficiency assessment and especially for the less developed area of biotic resources.

The fundamentals of input-output and hybrid LCA are covered in *Chap*. 6. Shinichiro Nakamura (Waseda University, Tokyo, Japan) and Keisuke Nansai (National Institute for Environmental Studies, Tsukuba, Japan) are leading contributors to this special type of LCA. Their comprehensive chapter introduces the basics of input-output analysis for LCA from a simple input-output model with one sector to complex multiregional extensions. Among others, the concepts of environmentally extended IO, different types of hybrid IO-LCA, and the waste IO (WIO) model are introduced. Tools and several databases for IO-LCA are presented and discussed. Several case studies demonstrate the potential and applicability of the approaches elaborated in this chapter.

Chapter 7 covers material flow analysis (MFA). David Laner and Helmut Rechberger from Vienna University of Technology, Austria, represent one of the leading groups on this topic established by Paul Brunner. They introduce the basic terms and procedures of MFA methodology from the selection of system boundaries, flows, substances, and processes to the presentation of results. Data reconciliation and uncertainty analysis are covered as well as the differences between static and dynamic MFA. Options for application including resource efficiency evaluation, identification of sources, sinks and final sinks, national materials accounting, or environmental impact assessment are introduced. Last, but not least, the combination of MFA and LCA is presented as a promising approach for environmental decision support.

The final *Chap*. 8 of this volume is dedicated to the life cycle assessment of organizations, such as organizational LCA. Julia Martínez-Blanco (Technische Universität Berlin, Germany; now at Inèdit, Barcelona, Spain), Atsushi Inaba (Kogakuin University, Tokyo, Japan), and myself represent the core leadership team of the flagship project of the UNEP/SETAC Life Cycle Initiative on this topic. As lead authors of the associated Guidance on Organizational LCA (UNEP 2015), we cover the topic also for this volume. After a brief sketch of the way toward LCA of organizations and an overview of existing initiatives for LCA of organizations, some of the main methodological issues of organizational LCA are discussed. They include the main differences with product LCA, reporting organization, reporting flow, system boundary, types of data, and prioritization of data collection efforts. For the practical implementation of organizational LCA, an approach of different implementation pathways is proposed. The chapter concludes with a presentation of early adopted case studies of Accor as a French international hotel group present in 92 countries with more than 3500 hotels and Unilever as an Anglo-Dutch multinational fast-moving consumer goods company with a wide-ranging portfolio in foods, household, and personal care products of around 400 brands.

4 Conclusion and Outlook

The establishment of the international standards of LCA (ISO 14040 series) was crucial for the broad acceptance of LCA all around the world and by all stakeholders. The standards contributed significantly to the transition of LCA from an academic toy or misused greenwashing machine toward a serious, robust, and professional tool to support decision-making in public and private organizations (Finkbeiner 2014b). At the same time, part and consequence of this success story is the increasing development of spin-off methods and tools built on LCA, which we call in this volume "Special Types of Life Cycle Assessment."

The special types of LCA address particular parts of LCA methodology or modeling, respectively, complementary methodologies (e.g., IO-LCA, MFA), new objects for the analysis (e.g., organizational LCA), simplified or single-issue types of LCA (e.g., carbon or water footprinting), or expanded versions of purely environmental LCA by addressing or including further sustainability dimensions (resource efficiency, life cycle costing, social LCA, life cycle sustainability assessment).

All these developments open up new opportunities for a credible and robust use of LCA for real-world decision-making in the sense of life cycle management and life cycle sustainability management (Finkbeiner 2011; Baitz et al. 2013). However, they may also pose certain threats to LCA as the core methodology if the proliferation trend leads to reduced consistency, scientific robustness, and information quality. More choice in the toolbox is a good opportunity for tailor-made solutions, but bears the risk of confusion, arbitrary choices, and inefficient competition.

Individualization and big data are among the megatrends of our societies. In that sense, it is more than likely that we will see a further blooming of special types of LCA. It is the challenging task of the global LCA community to support its growth by being as open, innovative, and market responsive as possible, but as conservative as necessary to safeguard the hard-earned credibility of LCA and its offspring. LCA and its special types are still more of a family business than an incorporated enterprise. Therefore, responsible growth and managing risks for the core product LCA appear more sustainable than jumping on every gravy train and selling out LCA to the max.

References

Baitz M, Albrecht S, Brauner E, Broadbent C, Castellan G, Conrath P, Fava J, Finkbeiner M, Fischer M, Fullana i Palmer P, Krinke S, Leroy C, Loebel O, McKeown P, Mersiowsky I, Möginger B, Pfaadt M, Rebitzer G, Rother E, Ruhland K, Schanssema A, Tikana L (2013) LCA's theory and practice: like ebony and ivory living in perfect harmony? Int J Life Cycle Assess 18:5–13

Berger M, Finkbeiner M (2013) Methodological challenges in volumetric and impact-oriented water footprints. J Ind Ecol 17:79–89

Finkbeiner M (2009) Carbon footprinting – opportunities and threats. Int J Life Cycle Assess 14 (2):91–94

Finkbeiner M (2011) Towards life cycle sustainability management. Springer, Berlin/Heidelberg. ISBN 978-94-007-1898-2

Finkbeiner M (2013) From the 40s to the 70s—the future of LCA in the ISO 14000 family. Int J Life Cycle Assess 18:1–4

Finkbeiner M (2014a) Product environmental footprint—breakthrough or breakdown for policy implementation of life cycle assessment? Int J Life Cycle Assess 19:266–271

Finkbeiner M (2014b) The international standards as the constitution of life cycle assessment: the ISO 14040 series and its offspring. In: Chapter 3 of Klöpffer W (ed) Background and future prospects in life cycle assessment. LCA compendium – the complete world of life cycle assessment, Springer, Dordrecht, pp 85–106, doi 10.1007/978-94-017-8697-3

Finkbeiner M, Wiedemann M, Saur K (1998) A comprehensive approach towards product and organisation related environmental management tools. Int J Life Cycle Assess 3:169–178

Finkbeiner M, Inaba A, Tan RBH, Christiansen K, Klüppel H-J (2006) The new international standards for life cycle assessment: ISO 14040 and ISO 14044. Int J Life Cycle Assess 11 (2):80–85

Finkbeiner M, Schau EM, Lehmann A, Traverso M (2010) Towards life cycle sustainability assessment. Sustainability 2:3309–3322

Galatola M, Pant R (2014) Reply to the editorial “Product environmental footprint—breakthrough or breakdown for policy implementation of life cycle assessment?” by Finkbeiner M. Int J Life Cycle Assess 19(2):266–271. Int J Life Cycle Assess (2014) 19:1356–1360

ISO 14040 (2006) Environmental management – life cycle assessment – principles and framework. Geneva

ISO 14044 (2006) Environmental management – life cycle assessment – requirements and guidelines. Geneva

ISO 14046 (2014) Water footprint – requirements and guidelines. Geneva

ISO/TS 14067 (2013) Carbon footprint of products – requirements and guidelines for quantification and communication. Geneva

ISO/TS 14072 (2014) Environmental management – life cycle assessment – requirements and guidelines for organizational life cycle assessment. Geneva

Klöpffer W (2014) Background and future prospects in life cycle assessment. LCA compendium – the complete world of life cycle assessment. Springer, Dordrecht. doi:10.1007/978-94-017-8697-3, 362 pp

Lehmann A, Bach V, Finkbeiner M (2015) Product environmental footprint in policy and market decisions: applicability and impact assessment. Integr Environ Assess Manag 11:417–424

Martínez-Blanco J, Inaba A, Finkbeiner M (2015a) Scoping organizational LCA – challenges and solutions. Int J Life Cycle Assess 20:829–841

Martínez-Blanco J, Inaba A, Quiros A, Valdivia S, Milà-i-Canals L, Finkbeiner M (2015b) Organizational LCA: the new member of the LCA family – introducing the UNEP/SETAC Life Cycle Initiative guidance document. Int J Life Cycle Assess 20:1045–1047

Martínez-Blanco J, Lehmann A, Chang YJ, Finkbeiner M (2015c) Social organizational LCA (SOLCA) – a new approach for implementing social LCA. Int J Life Cycle Assess 20:1586–1599

Maslow AH (1943) A theory of human motivation. Psychol Rev 50:370–396

UNEP (2015) Guidance on organizational life cycle assessment. Life Cycle Initiative, United Nations Environment Programme and Society for Environmental Toxicology and Chemistry, Paris, France, http://www.lifecycleinitiative.org/wp-content/uploads/2015/04/o-lca_24.4.15-web.pdf. Accessed 07 July 2015

Chapter 2
Carbon Footprint of Products

Atsushi Inaba, Sylvain Chevassus, Tom Cumberlege, Eunah Hong, Akira Kataoka, Pongvipa Lohsomboon, Corinne Mercadie, Thumrongrut Mungcharoen, and Klaus Radunsky

Abstract According to ISO 14040:2006 and ISO 14044:2006, the carbon footprint of products (CFPs) is the system to calculate the category indicator of the targeted product for the global warming potential or "climate change" in life cycle assessment.

There are many LCA studies focusing on greenhouse emissions. However, it is quite new to show consumers the calculation results on the shelves of supermarkets.

CFP started in the UK, and many countries followed. In this chapter, the background of CFP, the aims, and the relation to type 3 label known as ISO 14025:2006 are described in Sect. 2, followed by the general procedures of CFP and methodological issues of CFP.

A. Inaba (✉)
Department of Environmental and Energy Chemistry, Kogakuin University, 163-8677 Tokyo, Japan
e-mail: a-inaba@cc.kogakuin.ac.jp; inaba3423@gmail.com

S. Chevassus
French Ministry for Environnent, Energy and Sea (MEEM), La Défense cedex, 92055 Paris, France

T. Cumberlege
The Carbon Trust, SE1 9NT London, UK

E. Hong
Korea Environmental Industry & Technology Institute (KEITI), 122-706 Seoul, Republic of Korea

A. Kataoka
Japan Environmental Association for Industry (JEMAI), 101-0044 Tokyo, Japan

P. Lohsomboon
Thailand Greenhouse Gas Management Organization (TGO), 10210 Bangkok, Thailand

C. Mercadie
EMC Distribution Groupe Casino, 94400 Vitry sur Seine, France

T. Mungcharoen
National Science & Technology Development Agency and Faculty of Engineering, Kasetsart University, 10900 Bangkok, Thailand

K. Radunsky
Umweltbundesamt GmbH, Spittelauer Lände 5, 1090 Vienna, Austria

M. Finkbeiner (ed.), *Special Types of Life Cycle Assessment*, LCA Compendium – The Complete World of Life Cycle Assessment,
DOI 10.1007/978-94-017-7610-3_2

As the consumers can now compare CFPs directly in the store, it is needed to clarify the rules for the calculation and communication of CFP. In order to develop the internationally harmonized methodology of CFP, ISO/TS 14072 was published in 2013. In Sect. 3, the main discussion points are introduced, which were compromised when ISO/TS 14067:2013 was published.

In Sects. 4, 5, 6, 7, 8, and 9, the experiences of CFP in the UK, France, Japan, Korea, and Thailand are introduced.

CFP is the evaluation tool of the product focusing only on global warming, designed as "single criteria." Recently, the evaluation tool of the organization focusing on global warming has been paid attention, which is called "Organizational CFP" (ISO/TR 14069:2013). Moreover, the tools to evaluate more environmental categories than only global warming of the product and/or the organization are called "multicriteria."

In this chapter, the current status of CFP in the world is overviewed, and the outlook of CFP in the future is discussed. One of the reasons why CFP obtained such high attention in the society is that the consumers can see and compare CFPs directly in the store. CFP is expected to be a communication tool between producers and consumers. This is true in the present and will be true in the future.

Keywords LCA of organizations (ISO 14072) • Carbon footprint of products • CFP • Climate change • CO_2 • Consumer acceptance • Eco-label • European Commission • GHG Protocol • Global warming • Greenhouse gases • ISO 14020:2000 • ISO 14025:2006 • ISO 14040:2006 • ISO 14044:2006 • ISO/TR 14069:2013 • ISO/TS 14067:2013 • ISO 14072 • Multicriteria • PAS 2050 • PCR • Product category rules • Publicly available specification • Single criteria • Single impact • UNEP/SETAC Life Cycle Initiative

Acronyms

ACFN	Asia Carbon Footprint Network
AHG	Ad hoc group
BSI	British Standards Institution
CBO	Carbon Business Office
CFP	Carbon footprint of products
CSR	Corporate social responsibility
EF	GHG emission factor
EPD	Environmental product declaration
GHG	Greenhouse gases
GWP	Global warming potential
IPCC	Intergovernmental Panel on Climate Change
PAS	Publicly available specification
PCRs	Product category rules/environmental product declarations
SCP	Sustainable consumption and production

SKU	Stock keeping units
TGO	Thailand Greenhouse Gas Management Organization
UNCED	United Nations Conference on Sustainable Development
UNESCAP	Economic and Social Commission for Asia and the Pacific
UNFCCC	United Nations Framework Convention on Climate Change
WBCSD	World Business Council for Sustainable Development
WRI	World Resources Institute
WTO CTE	Committee on Trade and Environment of the World Trade Organization

1 Introducing "Carbon Footprint of Products"

Atsushi Inaba
Department of Environmental and Energy Chemistry, Kogakuin University, 163-8677 Tokyo, Japan

1.1 Outline of the Chapter

This chapter overviews the status of the "carbon footprint of products" (CFPs). It is presented in six main sections. First, the features, the aims, and the general implementation method of CFP are introduced, followed by the methodological issues of CFP discussed in Sect. 2. In Sect. 3, the main discussion points in connection with the publication of ISO/TS 14067:2013 (ISO 2013a) are explained including arguments from several countries. In Sects. 4, 5, 6, 7, 8, and 9, the world activities on CFP are introduced in the UK, France, Japan, Korea, and Thailand.

1.2 What Is Carbon Footprint of Products?

The CFP displays the greenhouse gas emissions associated with the life cycle of commercial goods on the packages in supermarkets. This development started in the UK in 2007. PepsiCo was one of the first companies to calculate, certify, and display the product carbon footprint on their potato chips. Since 2007, over 28,000 individual stock keeping units followed, independently certified by Carbon Trust for 178 organizations around the world, which means in 27 different countries and on every continent (Fig. 2.1). Also in France, Casino, in one of the supermarket chains, started in 2008 the sales of some foods showing the greenhouse gases on their packages (Fig. 2.2).

Fig. 2.1 Carbon footprint declaration from Carbon Trust, UK, when CFP started in 2007–2008 (Photo from Tom Cumberlege, Carbon Trust, see Sect. 4)

Fig. 2.2 Carbon footprint declaration from Casino, France (Photo from Corinne Mercadie, see Sect. 6)