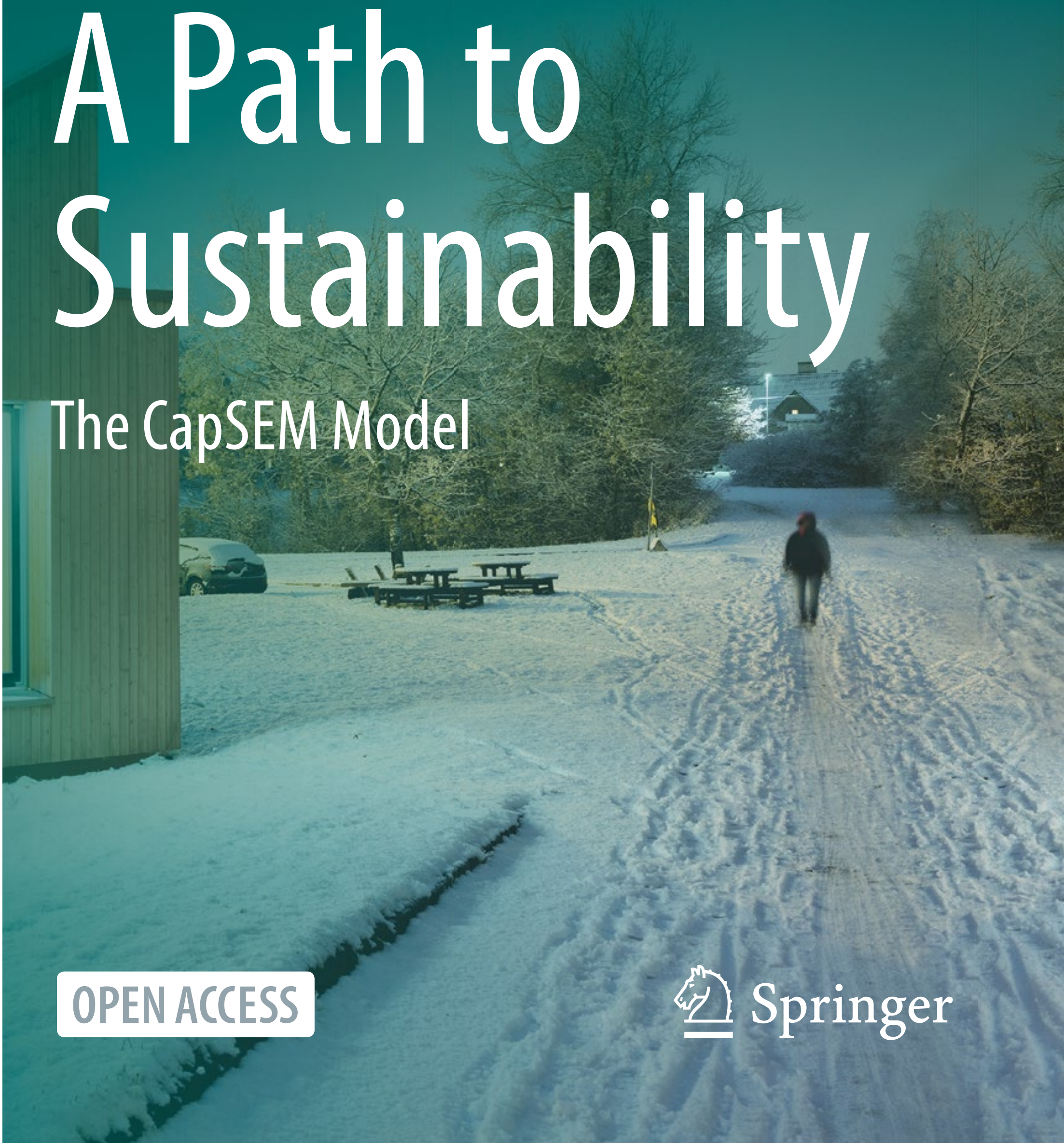
Annik Magerholm Fet *Editor*

Business Transitions: A Path to Sustainability

The CapSEM Model



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Foreword by Bjørn K. Haugland

I first met Professor Annik Magerholm Fet some years ago. As Chief Sustainability Officer for Det Norske Veritas (DNV), I was heading up a project to explore how global risks could be converted into opportunities. One of our junior employees at that time insisted on his former supervisor from NTNU being consulted. I was immediately impressed by the way Annik supported us with deep insights alongside a systemic view and practical advice. The book you are about to read represents precisely that approach.

Together with a team of colleagues, many of whom are former PhD students of Professor Fet, *Business Transitions: A Path to Sustainability* offers a clear view on the transition to a safe and sustainable future by providing a holistic approach to the transition to sustainability alongside a toolbox of practical methods and tools.

Over the last 15 years, I have guided CEOs and executive leadership teams on how to best position their companies to build competitive capabilities in the transition to a more sustainable future. Two years ago, I started in my current role as CEO and co-founder of Skift Business Climate Leaders, a network of 50 companies accelerating the green transition of Norway. As part of this, I work closely with governments and academia. There is a growing awareness of the need for action. And with that, a need to build competence and share best practice is growing across all sectors of society.

It is indeed time to act.

Secretary-General António Guterres calls the latest IPCC Climate Report (2021) 'Code Red for Humanity'.

The alarm bells are deafening, and the evidence is irrefutable: greenhouse-gas emissions from fossil-fuel burning and deforestation are choking our planet and putting billions of people at immediate risk. Global heating is affecting every region on Earth, with many of the changes becoming irreversible.

Sustainability is about much more than climate change. Still, a code red alert on the need to decarbonize all sectors pinpoints that failing climate change will be a significant barrier to achieving the other Sustainable Development Goals (SDG). *Business Transitions: A Path to Sustainability* has adapted this approach by keeping a strong focus on environmental sustainability and at the same time highlighting the holistic overview of SDGs.

Going forward, responding to the challenge posed by sustainability will transform society and business, and greatly affect future solutions and competitiveness. Sustainability becomes an important driver for business development, increasing the need for better methods and accessible tools for analysis and development. This book is a valuable contribution as it presents a toolbox for achieving sustainability.

A net zero society requires more resource-efficient production and use. *Producing more with less* means more use of renewable resources, both as raw material and as an energy source, and more recycling and reuse of materials and products that contribute to *closing the loop*.

Approaches to sustainability and a green transition invite a new way of thinking, with an increased emphasis on assessing and designing systems and relationships. This approach is broad and comprehensive, with a far wider scope than simply greenhouse gas emissions. All significant energy, material and commodity flows, and how these affect resource use and emissions, must be assessed. Value chains and life cycle thinking for the products will play a key role, often related to socio-economic systems such as energy, cities, food and land use, water, transport and industry. Value creation, creating jobs and emission reductions will be linked, so that green competitiveness can be more specified and strengthened and enhance social well-being and life quality.

In a green transition, the corporate framework will change, and the changes will impact opportunities and threats in business development to a high degree. The market, technology and regulatory frameworks will also change. A sustainable welfare society, as well as business practice, needs new knowledge and solutions to move towards a sustainable future. This involves developing new tools and novel management concepts.

The following trends for development will be relevant for all sectors:

- *Life cycle perspectives and value chains* will have an increasing role and importance.
- *Roadmaps* for different sectors in society and across sectors will help to identify and analyze connections, problems and solutions.
- *Uniform and comparable reporting* will provide owners and managers of capital with a common decision basis on sustainability issues such as climate risk.
- *Product requirements and product information* will be strengthened, giving manufacturers, customers and consumers a better basis for product selection.
- *Green procurement*, both public and private, must be based on relevant criteria.
- Purchasing requirements should be functionally oriented and based on life cycle assessments.
- *Policy design and policy instruments will* change markets and the demand for technical solutions. The design of economic and regulatory instruments is often crucial for competitiveness and the pace of implementing new solutions.
- *Emerging technologies* will have to meet sustainability requirements and must be integrated with disruptive innovation strategies.

This book responds to many of the above needs by providing sound methods and a feasible toolbox for sustainable specification and analysis. The tools presented are explicit and extensive while discussing aspects and tools for innovation and business development on a structural level. In particular, the tools can be applied to market and technology development and policy instruments. The book presents a solid foundation for practical development and the implementation of new green solutions.

The transition to a low-emission society requires generating and sharing new knowledge. Academia develops new knowledge, and when shared with companies and businesses, that results in practical results.

The contributors to this book have been deeply involved in the issues and tools presented and have experience with implementation in companies. Learning by doing through collaboration between companies, academia and interest groups will continue to be an important driving force in the further development of work on sustainability. For example, cooperation on environmental reporting and later sustainability reporting have been important for raising awareness and action in many companies. Work with corporate social responsibility, life cycle analyses and industrial ecology have also significantly benefited from the interaction between academia and companies. Systems thinking is expected to benefit from the interaction between theory and practical application too.

The need for competence building in the area of sustainability has never been greater: in society, among researchers and students, in the business sector, and for interest groups and governments. This book inspires further knowledge-based development and creates opportunities based on ambitions, analysis and facilitation of implementation. The content is theoretically well-grounded, whilst oriented towards practical application.

I am confident that this book will become a useful workbook for both leaders and practitioners in government and business, as well as for students.

CEO Skift, Business Climate Leaders
Oslo, Norway
July 1st, 2022

Bjørn K. Haugland

Foreword by Fritz Balkau

For some years now the environmental management vision has turned: preferring prevention to remediation, the latter having proven to be both costly and inefficient. Specific instruments and policies were subsequently devised to facilitate such prevention approaches, with both the targets and the tools increasing in sophistication and applicability. But independent isolated measures inevitably have limited success, and efforts turned towards developing universal toolboxes that allow managers and policymakers alike to better deal with ambitious sustainable development goals. The CapSEM Model and its underlying toolbox is the latest, and perhaps the most comprehensive, recent initiative to assist organisations – both public and private – to more systematically address complex global problems, whilst simultaneously making business sense. The present CapSEM Model allows the current generation of managers and policymakers to move forward to confront our common sustainability challenges whilst also providing an effective platform for further methodological evolution.

International Adviser, Sustainable Solutions — Fritz Balkau
August 8th, 2022

Preface

Sustainability and Business Challenges

Over the last few decades, excellent concepts and tools have been developed for business and organizations to address environmental and sustainability challenges. The contributors to this book have, for a long time, been deeply involved in developing such tools and have many years of experience implementing them in companies. It is an area to which I have devoted over 30 years of my academic and research life. This publication therefore represents and reflects that body of work and the expertise accumulated, shared, and advanced through research, teaching, and supervising PhD students in this field.

The volume focuses specifically on the environmental dimensions of Sustainable Development (SD), and presents analytical tools, from a site perspective to a life cycle perspective. It presents and discusses a significant compilation of concepts and tools regarding their background, method, and practical application. The tools are gathered and summarized in a toolbox, giving consideration to the way in which they have been developed and subsequently implemented by the industry over time. A significant contribution of this book is the efforts to systematize concepts and tools in relation to four levels of development: processes, products, organization, and systems. Together with examples of practical application, this increases insights into existing possibilities and opportunities for further development to meet business requirements in sustainability. The book further discusses how the tools relate to corporate practice seen from the perspective of sustainability, and finally raises some critical questions around the extent to which these tools have supported companies in their advances toward more sustainable attitudes, values, and practices.

The combination of technological development and sustainability raises the challenge for industrial development to think, plan, and produce in accordance with ecological principles. This is the philosophy behind Industrial Ecology, which is discussed in a separate chapter of this volume. Systems thinking and a life cycle approach are essential in the work for SD and, as such, permeate the volume. While the emphasis is on technological issues in accordance with ecological objectives rather than discussing political decision-making or societal matters of sustainability, in Part IV, a systems thinking approach allows reflection on the consequences of the application of these tools in academic as well as legal and societal settings.

The book is divided into four parts as follows.

Part I, entitled Sustainability challenges and opportunities, sets the context for the following three parts of the book in 3 chapters focusing on sustainability challenges, the components of the toolbox in the CapSEM Model, and the role of the CapSEM Model in terms of the Sustainable Development Goals (SDGs). The critical discussion of the tools, their implementation, and the flexibility of this model which is continuously developing is a cross-cutting theme throughout the book.

Part II, entitled The toolbox: Methodologies and theory, builds on the CapSEM Model presented in Part I and further explains each level in the toolbox. Chapters 4 and 5 deal with Level 1, Chaps. 6 and 7 with Level 2, Chaps. 8 to 10 with Level 3, and Chaps. 11 and 12 with Level 4. The toolbox in Part II is broken down into its constituent parts with detailed explanations for each.

Part III, entitled From theory to practice, builds on the theoretical model of the toolbox set out in Part II. There are a range of innovative and thought-provoking case studies which exemplify in detail how the constituents of the toolbox are put into practice. These implementations appear across a range of very different business sectors, demonstrating the usefulness, feasibility, and flexibility of the tools. Many of the sectors included in these case studies are listed under the Circular Economy Action Plan in Europe and were chosen for inclusion for that reason.

Part IV deals with The road ahead. The concluding part of the book looks at possible and desirable futures for further development and implementation of the toolbox. Chapter 21 summarizes the application of the tools and put attention to the need for transdisciplinary collaboration in the transition to sustainability. The objective is to identify benefits and challenges for capacity building in sustainability. Chapter 22 looks at organizations' approaches to environmental management tools and the way in which interaction and transdisciplinary collaboration in a wider system can contribute to moving toward sustainable societies. Chapter 23 discusses how the innovative mechanisms in sustainable business models may be expanded further to encompass all dimensions of sustainability and pervade fully through organizations.

Chapter 24, or the conclusion, attempts to provide an outlook for business, organizations, and societies applying the tools while moving toward a sustainable future. The need for competence building in sustainability is increasing in society, among researchers and students, in the business sector, and for interest groups and governments. The purpose of this book should be to inspire knowledge-based development, make visible opportunities based on business ambitions, and facilitate implementation of new solutions. The content is theoretically well grounded, while also oriented toward thoroughly practical application.

This book can be used as both a beneficial, and useful, workbook for practitioners. Conceivable future developments or applications of the model, not addressed in this publication, could target learnings for developing countries, transferring the lessons learnt elsewhere in adopting SDGs to the needs of diverse economic and cultural settings. This is aligned with the laudable objective of the U.N. motto 'Leave no one behind' and requires a systemic approach across local, national, and international organizations. The journey, described, considered, and analyzed in this publication, continues to be a potential catalyst toward a path to be encountered, embraced, and traveled by multiple actors, across a range of domains, using multi-level systems.

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Annik Magerholm Fet

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There are many people I want to thank for their assistance in writing this book.

Firstly, I would like to thank my colleagues and former PhD students for inspiring discussions and contributions to this book. In addition to the few I have mentioned below, there are numerous individuals and organizations that have contributed, and the book would not have been the same without these valuable inputs. I have gained experience from working together with business leaders implementing the tools presented in this book, and the CapSEM Model is a result of positive collaboration with practitioners over a long period of time.

The toolbox presented in the CapSEM Model has been tested in many projects with business partners. One of the most recent was the Erasmus+ project with the same name which I led as a Professor at NTNU. Thanks to all contributions from colleagues at TU Delft and University in Lisbon. Many thanks also to our partners in Uganda, India, and Nepal.

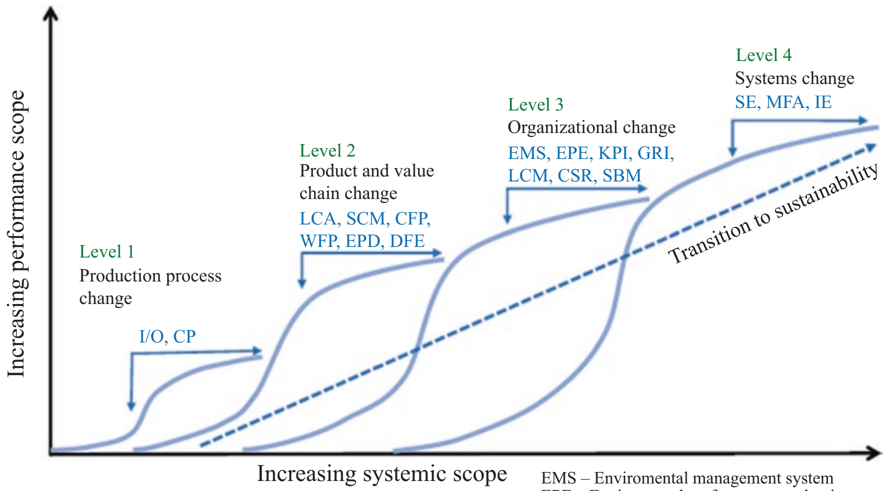
My gratitude is extended to Bjørn Haugland for writing the Foreword, and his enthusiasm and engagement for a shift toward sustainability in business future practice. Also to Fritz Balkau for his Foreword and his long-held and continued commitment to expertise in this area of research and teaching.

Special thanks to the Internal Editorial Team:

- Professor Martina Keitsch for many good discussions on the overall structure of the book, for input on the field of environmental practices and governing principles, and her excellent scientific contributions to the text, especially Parts I and IV.
- Associate Professor Cecilia Haskins for her contributions toward the book, and to the final stages of compiling it, especially for her help in the final editing of Parts II and III.
- Adjunct Associate Professor Sandra Elizabeth Tippett-Spirtou for her work in coordinating the work on my behalf as the editor and main author, representing all the co-authors of this book, and keeping a tight timeline for fulfilling the requirements set by the publisher.

Finally, I would like to thank the publisher for organizing the work between the many partners involved.

CapSEM Model



I/O – Input-output analysis
CP – Cleaner production
LCA – Life cycle assessment
SCM – Supply chain management
CFP – Carbon footprint
WFP – Water footprint
EPD – Environmental product delcaration
DFE – Design for environment

EMS – Enviromental management system
EPE – Enviromental performance evaluation
KPI – Key performance indicator
GRI – Global Reporting Initiative
LCM – Life cycle management
CSR – Corporate social responsibility
SBM – Sustainable business model
SE – Systems engineering
MFA – Material flow analysis
IE – Industrial ecology principles

Capacity building in Sustainability and Environmental Management (CapSEM) Model: a systemic approach towards sustainability. (Modified from (Fet and Knudson 2021)

Contents

Acronyms

ABC	Activity-based costing
AC	Activated charcoal
ALDFG	Abandoned, lost or otherwise discarded fishing gear
BM	Business model
BMfS	Business model for sustainability
BMI	Business model for innovation
BMIfS	Business model innovation for sustainability
B2B	Business-to-business
B2C	Business-to-consumer
BOM	Bill of materials
BOP	Bottom of pyramid
BREEAM	Building research establishment environmental assessment method
BS	British standard
CapSEM	Capacity building in sustainability and environmental management
CE	Circular economy
CFP	Carbon footprint of product
CO_2	Carbon dioxide
CP	Cleaner production
CPA	Cleaner production assessment
CSR	Corporate social responsibility
DfE	Design for environment
DfS	Design for sustainability
DfX	Design for X principles
DSB	Norwegian Directorate for Civil Protection (Direktoratet for Sivilt Beredskap)
DPSIR	Driver-pressure-state-impact-response
EA	Environmental auditing
EC	European Commission
ECI	Environmental condition indicator
ED	Eco-design
EI	Environmental indicator

EIA	Environmental impact assessment
EMAS	Eco-management and audit scheme
EMS	Environmental management system
EOL	End-of-life
EP	Environmental performance
EPE	Environmental performance evaluation
EPD	Environmental product declaration
EPI	Environmental performance indicator
ESG	Environmental social and governance
FU	Functional unit
GHG	Greenhouse gases
GRI	Global reporting initiative
GSS	Green supplier selection
HSE	Health, safety and environment
IE	Industrial Ecology
IM	Industrial Methabolism
I/O	Input-output
IOT	Internet of things
IS	Industrial Symbiosis
ISO	International Organization for Standardization
KPI	Key performance indicator
LA21	Local agenda 21
LCA	Life cycle assessment
LCC	Life cycle costing
LCM	Life cycle management
LEED	Leadership in energy and environmental design
LNG	Liquefied natural gas
MBC	Material-based cost
MET	Material, energy and toxicity
MFA	Material flow analysis
MGO	Marine gas oil
MIA	Material intensity analysis
MIPS	Material input per service unit
MPI	Management performance indicator
NGO	Non-governmental organisation
NO_x	Nitrogen oxides
NMA	Norwegian maritime authority
NRBV	Natural resource-based view
OECD	Organisation for economic co-operation and development
OPI	Operation performance indicator
PM	Particulate matters
PCB	Polychlorinated biphenyls
PCR	Product category rules
PDCA	Plan-do-check-act
PEF	Product environmental footprint

PSR	Pressure state response
PVC	Polyvinyl chloride
QAM	Quality assurance manual
RI	Radical Interdisciplinarity
SCM	Supply chain management
SCR	Selective catalytic reduction
SD	Sustainable development
SDG	Sustainable development goal
SE	Systems engineering
SETAC	Society of Environmental Toxicology and Chemistry
SFA	Substance flow analysis
SM	Systems methodology
SSCM	Sustainable supply chain management
SVC	Shared value creation
TBT	Tributyltin
TCM	Technical cost modelling
UN	United Nations
UNCSD	United Nations' Commission of Sustainable Development
UNEP	United Nations environmental Programme
USEPA	US Environmental Protection Agency
VAA	Value-added analysis
VOC	Volatile organic compound
VWTP	Valley waste treatment plant
WBCSD	World business Council for Sustainable Development
WFP	Water footprint of product
WRI	World resources institute

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Part I
Sustainability: Challenges and Opportunities

Chapter 1
Business Challenges in the Transition to Sustainability

Annik Magerholm Fet and Martina Keitsch

Abstract The first chapter of this book presents a brief history of Sustainable Development (SD) and takes a closer look at business and industry and their attitudes and actions towards sustainability regarding technological development, environmental issues and challenges for organizations. The goal of the chapter is to advocate for the growing need for competence building in sustainability amongst business leaders as well as societal stakeholders. It prepares the reader to understand how this can be done via the tools and strategies that are discussed in the following chapters of this book.

1.1 Introduction

Advancing the Sustainable Development Goals (SDGs) of the United Nations 2030 Agenda is a globally recognized aim. National governments and societies across the world are launching SDG-based strategies or aligning their existing policy plans and objectives with the SDGs. As the United Nations stated in their Preamble:

> The 17 Sustainable Development Goals and 169 targets which we are announcing today demonstrate the scale and ambition of this new universal Agenda. (UN 2015).

In terms of business, the SDGs include, amongst others, an obligation for industry to adhere to in order to realize SD standards. The World Commission on Environment and Development also known as the Brundtland Commission (Brundtland 1987) coined the definition of SD, a predecessor of the SDGs, as:

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

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Besides emphasizing the needs of both present and future generations, SD is also concerned with meeting the triple bottom line – social, environmental and economic aspects – also referred to as *people, planet and profit*. The triple bottom line represents a dynamic balance that must be maintained between human activities, technologies, natural environmental capacities, human requirements, living standards, goals and values (Ehrenfeld 1994). Even if SD is considered a metafix by some authors (e.g. Lele 2018), the concept provides an agenda and direction for further global decision-making, research and development.

Both the SDGs and SD require expanding the scope of traditional business management and reporting, for example, to explicitly include social and environmental aspects in organizational reporting in addition to its economic performance and its products and services. Both the SDGs and SD have their roots in the environmental crisis of the late 1970s.

1.1.1 Historical Background

As factories materialized in increasing numbers (mainly in the United Kingdom) in the late 1800s, environmental impact on the surrounding land and air also increased. Smoke was released into the air and pollution belched into streams and lakes leading to acidification, fish-death and biodiversity degradation. With no laws in place to stop this, emissions quickly escalated.

In 1952, London's 'Great Smog' killed an estimated 12,000 people and gave rise to the Clean Air Act (1956) in an attempt to control domestic sources of air pollution. A subsequent Clean Air Act was passed in 1968. Regulating the minimum heights of chimneys, air pollution conferred with the motto 'Dilution is the solution to pollution'. It required chimney stacks in and near towns to be built up taller to push pollution away from inhabitants. Neither act considered reducing factory emissions or their role as significant air polluters (Shorthouse and Nicolle 2019).

Rachel Carson's book *Silent Spring,* published in 1961, Paul Ehrlich's *The Population Bomb* from 1968 and particularly, the Club of Rome's report '*Limits to Growth*' (Meadows et al. 1972) served as wakeup calls for a necessarily broader sustainability quest, expanding from earlier environmentalism perspectives largely concerned with protecting wild land (Keitsch 2018). Some authors also claim that the discourse on the environment was driven by the fact that the exhaustion of natural ecosystems had shown severe consequences not only for nature, but also for humans and society itself (Odum 1998). Changes in the natural environment placed the social environment under pressure to change. Environmental concerns were partly triggered by fears that economic growth might endanger the survival of the human race and the planet, expressed by authors such as Glick: "…if we continue our present practices, we will face a steady deterioration of the conditions under which we live" (Dubos et al. 1960).

In 1972, the United Nations Conference on the Human Environment Declaration (the Stockholm Declaration) recognized that: "In our time, man's capability to transform his surroundings, if used wisely, can bring to all peoples the benefit of development and the opportunity to enhance the quality of life. Wrongly or heedlessly applied, the same power can do incalculable harm to human beings and human environment." Furthermore, Article 3 stated: "To defend and improve the human environment for present and future generations has become an imperative goal for mankind." This conference brought politicians' attention to the rising problem of pollution, pesticides, and other issues faced on a global scale. It was one of the first times a political meeting had such an overwhelming number of citizens attend. Disastrous events such as the Minamata Disaster in 1950, in which 1785 people died from methylmercury leaking into waterways, and the impact of Agent Orange on humans in Vietnam, were brought to the table.

Despite various policies and acts formed after the 1970s, their implementation in different societal sectors halted, and hence lacked rapid progress. In the 1980s, climate change was introduced to the growing list of global environmental challenges, later summarized in the Kyoto protocol (United Nations 1998). In addition, the discovery of the depletion of the ozone layer over Antarctica led to an increase in research on the impact of greenhouse gas emissions and chemicals on the atmosphere and ozone layer. As a result, ozone depleting chemicals were either regulated or banned by international laws by the late 1980s (Montreal Protocol 1987).

In the last decade of the twentieth century, increasing concern about the way in which human activities affect natural systems evolved amongst various stakeholders across society. Although there was some dispute over the rate of change, most scientists, researchers and decision-makers accepted that the challenges of the new millennium comprised the loss of biodiversity, thinning of stratospheric ozone, climate change and the collapse of natural resource stocks. The Brundtland report was presented at the UN Rio-Summit in 1992. It became a core document for decades to come (United Nations 2007).

SD topics and policies were further debated at the RIO + 10 summit in Johannesburg in 2002 (World Summit on Sustainable Development 2002) and the RIO + 20 summit in Rio de Janeiro in 2012. The summit in Johannesburg gathered hundreds of Heads of State and government and tens of thousands of government representatives and non-governmental organizations. The 'Rio + 20 summit', officially called the United Nations Conference on Sustainable Development (UNCSD), was attended by multinational companies and world leaders, with countries less well represented (United Nations 2012). The report 'The Future We Want' sets out broad sustainability topics such as Poverty Eradication, Food Security and Sustainable Agriculture, Energy, Sustainable Transport, Sustainable Cities, Health and Population, and Promoting Full and Productive Employment, clearly pointing towards the Sustainable Development Goals (European Environment Agency 2012).

According to some authors (Van Dieren 1995; Kassel et al. 2018; Keitsch 2021), SD also contributed to a change in mindset of societal actors from focusing on *problems,* to an interest in feasible, accessible and flexible *solutions* for SD. To ensure consensus on the need for progress, collaboration among stakeholders is essential, hereunder including governmental agencies, industry, non-governmental organizations (NGOs), research and academic institutions, individual citizens such as neighbours, voters, employers, investors, consumers and so on.

Moreover, to avoid dramatic incidents, the push towards integration of economic, social and ecological issues also requires the integration of all other relevant stakeholders. This became even clearer around the millennium and was brought to attention and reflected in the United Nations Millennium Development Goals, which guided sustainable development actions from 2000 to 2015 (United Nations 2000). Al Gore's 2006 book and documentary, *An Inconvenient Truth*, brought attention to extreme weather problems caused by global warming and simultaneously pinpointed the risk of social disturbances, injustice and wars caused by environmental disasters.

In 2015, 193 countries agreed to adopt the SDGs for the period 2015–2030. They are meant to encourage the international community to move towards a global sustainable future over the next few decades, and are part of the 2030 Agenda, officially known as "Transforming our World: the 2030 Agenda for Sustainable Development", agreed at the UN Sustainable Development Summit in September 2015 (United Nations 2015). The SDG framework is comprised of 17 goals and 169 targets that succeed the eight Millennium Development Goals. The SDGs set a very ambitious range of goals relevant for regional, national and global issues. Human development across triple bottom line dimensions (social, economic, and environmental) is central to the set of goals. Advancing the SDGs of the UN 2030 Agenda is warranted globally, and national governments all over the world continue to launch SDG-based development strategies, or align their existing policy plans with the proposed goals. The aim of these SDGs is, amongst others, to end poverty, fight inequality, protect biodiversity on land and in the oceans and urge efforts related to slowing down climate change.

In the preceding two decades, sustainability challenges have transformed society and actors such as industries and businesses. They have influenced the development of solutions and guided competitiveness toward solving these ecological and social business challenges. It is crucial to acknowledge the history and development of this movement, not only for further education, knowledge sharing and inspiration, but also to understand that all endeavours to move the world towards sustainability are part of a long line of activism. The global ecology movement has reached every corner of the world, and while sustainable activities contribute to edging the planet back from the brink of environmental disaster, ecological challenges grow ever more daunting (Weyler 2018).

As this brief introduction illustrates, the concept of SD has not only undergone huge transformations since its first definition by the Brundtland commission in 1987, but has also become much more specific in many areas. SD has been continually revised, addressing areas of knowledge identified and innovation taking place as new challenges arise.

The following section takes a closer look at business and industry and their attitudes and actions towards sustainability.

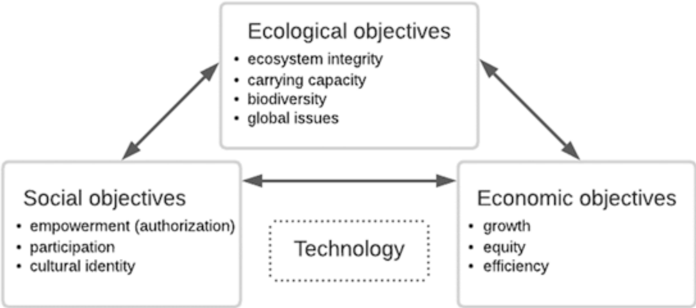

Fig. 1.1 Interrelationships between ecological, social and economic objectives for sustainable technology development. (Fet 1997)

1.1.2 Technology Development and Sustainability

The concept of sustainability now differs from former views of environmental value and the way in which social strategies were designed. Amid several assumptions, former frontier economists assumed that the earth was limitless in its capacity to support human society, that the future is created through price systems based on a free market and that technology is good and the solution to all problems (Ehrenfeld 1994).

In a narrow economic definition, sustainability comprises the maintenance of human-made capital (Bartelemus 2002). Social sustainability includes human rights, moral and social justice and natural capital stock of environmentally available assets such as soil, the atmosphere, forests, water and wetlands. To avoid compartmentalization, in which each societal actor pursues their own idiosyncratic sustainability strategy, different domains should be encouraged to collaborate and support each other. For example, technology must be designed to adjust to ecological, social and economic objectives. An important challenge for companies worldwide is the development of sustainable technologies that fit in with an integrated system of ecology, economy and social needs in a long-term perspective (Keitsch 2021). Technology development in relation to triple bottom line objectives is illustrated in Fig. 1.1. Social objectives include empowerment, participation and cultural identity, while economic objectives address equity and efficiency to support growth. Ecological objectives must secure ecosystem integrity and support the earth's carrying capacity and biodiversity.

1.1.3 Categorising Environmental Issues

There are many ways to categorize the environmental issues behind ecological objectives. According to OECD, they were grouped into four main categories of impacts (Gouzee et al., 1995) caused by (1) use of natural resources; (2) flows of pollutants and emissions; (3) reshaping of environment and changes of ecosystems, and (4) effects on human welfare caused by the condition of the environment. The type of impact can be identified based on the exchange of particular substances between technology and the environment (Fet 1997). The use of raw materials involves the extraction of substances from the environment, while emissions are the release of substances into the environment. Both extraction and emissions play a role across environmental issues. The most prominent environmental issues, or impact categories, are loss of biodiversity, climate change, depletion of the ozone layer, acidification of soils and lakes, eutrophication of water bodies, toxification of soils, water bodies and ecosystems, and accumulation of solid waste in nature. These categories can be further classified according to their global, regional and local impacts, as here exemplified by climate change, acidification and air quality.

1.1.4 Challenges for Business

Industrial companies are increasingly concerned about the impacts of their processes, products and services, all while searching for balance between profitability and sustainability. Without a reasonable degree of profitability, a private company cannot continue to function. This applies to both large and smaller companies. Small and medium sized companies (SMEs) are less robust financially and will in many cases take a reactive, rather than a proactive approach to addressing environmental challenges. The question, however, surrounds how environmental improvement measures will benefit the company. Historically, there has been a general notion that sustainability measures implicate higher costs which cannot be justified from the perspective of cashflow. In many cases this was probably correct and relatively few companies employed a proactive attitude. However, with growing need and pressure on a global scale, industrial companies increasingly use environmental performance as an element in their marketing efforts to meet their customers' demands and in an attempt to give their products added value.

Long term competitiveness on the market seems to be the most important motivation. Businesses increasingly request information and seek out tools to understand the environmental aspects and related impacts from their processes, products and services. Rapid green transition influences businesses' competitiveness based upon changes in markets, in technologies and in authorities' frameworks. Changing markets are driven by increased environmentally conscious demand and willingness to pay for environmental benefits, from individual consumers, to purchases by private businesses and via public sector procurement. A changing technological landscape, often driven by adaptations in authorities' frameworks to place penalties, taxes and fees on pollution, supports the development and implementation of new and emerging technologies.

Despite the drivers for change, most industrial companies do not have a comprehensive sustainability policy that covers all of their activities. In most cases, they only react when a business advantage is apparent or when market pressure, legislation or international treaties force them to react. Most companies also tend to have a strategic planning perspective for the short-term, for example 3–5 years. What happens 20–30 years later has less influence on their decisions now unless indisputable consequences can be amply demonstrated.

This might also hamper a critical re-thinking of industrial practices from industry until pressure for change is much more compelling. Such pressure will include economic incentives and social inputs into industrial decision making. Furthermore, mechanisms will have to be created to foster the goal of balancing industrial activity, the environment and equity concerns. This can be achieved if companies adopt system-oriented strategies to satisfy a growing demand for *green* products.

System-oriented strategies and holistic life cycle perspectives can be designed from both top-down and bottom-up approaches. A bottom-up approach often starts with an overview and understanding of the most significant aspects of sustainability connected to production systems and moreover to products and their material value-chains. Such strategies therefore depart from the possibility of increased resource efficiency, reduction of wastes and emissions at the production site and across the various parts and stages of the product value chain. Strategies are frequently built on principles of *good housekeeping* and implemented through internal control systems which are also a mechanism for ensuring rules and regulations are met. A top-down approach, on the other hand, often results from overarching challenges, such as the company's contribution to reducing the impact on climate for the sector. Companies are confronted with a wide range of demands through stricter regulations, standards and legislations. Business strategies are often developed based on a vision of achieving goals according to those presumed most important for the company. Procedures, regarding internal and external performance on different systems levels, will then be developed in order to implement those strategies.

Regardless of whether the approach is top-down or bottom-up, a set of guiding principles can be helpful. The purpose of the CapSEM Model presented in Chap. 2 is to provide guidance to companies about the availability of actual tools to analyse the environmental aspects and impacts of their processes, products and services, and to further theory on how to build competence and understanding surrounding the application of these tools in their stepwise transition towards sustainability.

1.2 Conclusion

This chapter started by tracing the history of SD, and concludes with an emphasis on the growing need for sustainability competence building in the business sector and for their stakeholders and other societal actors. The tools presented in the following chapters are provided to both inspire further knowledge-based development and create opportunities based on analyses and raised ambition, and to further support and facilitate the implementation of more sustainable solutions. The content is not only well-grounded in theory, but also oriented towards practical application.

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Chapter 2
The CapSEM Model

Annik Magerholm Fet and Haley Knudson

Abstract Organizations may feel pressurized to improve their sustainability performance and increase their orientation towards sustainability, but may not have either the knowledge as to where, or the capacity, to begin. This chapter therefore presents a systematized methodology of assessment and management tools for sustainability and environmental management known as the Capacity building in Sustainability and Environmental Management Model (the CapSEM Model). To help streamline their application for the business sector and industry, the methods and tools are positioned in relation to four levels of development: (1) *production processes*, (2) *products and value chains*, (3) *organization and management* and (4) *larger systems*, for example, industrial sectors or social systems.

The discussion and analysis of tools presented in this chapter and explained throughout this book, address the growing need to engage stakeholders and to consider environmental, social and economic impacts across the entire life cycles of products in business strategies and organization management. The CapSEM Model Levels move from incremental business tools and their application in production processes, to holistic tools for change in organizations and larger systems. The transition to sustainable societies is considered analogous to growth in both systems and performance complexity.

Extensively modified from Fet and Knudson (2021).

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2.1 Introduction

Responding to requirements for global sustainable development (SD) in society, information and teaching materials as well as significant environmental assessment tools for various industry sectors have been continuously developed and improved over the last 30 years. This chapter presents a systematized methodology for positioning some of these tools for the business sector and industry in relation to four levels of development: (1) *production processes*, (2) *products and value chains*, (3) *organization and management* and (4) *larger systems*, for example, industrial sectors or social systems. Organizations often do not have an overview of these tools, and the knowledge and capacity needed to implement them. Small and medium companies with more limited resources may especially find this challenging (Perez-Sanchez et al. 2003).

As internal and external requirements become increasingly stringent to meet growing sustainability challenges, companies and organizations need a holistic toolbox to help them navigate the interacting systems of SD, from triple-bottom-line aspects to geographic scopes and long-term dynamics. The Capacity building in Sustainability and Environmental Management Model (the CapSEM Model) is therefore presented as a methodological framework of the four Levels described above. These Levels move from incremental business tools and their application in production processes (Level 1) and value chains (Level 2), to more holistic tools for change in organizations (Level 3) and larger systems (Level 4).

The discussion and analysis of tools for assessing environmental impacts presented throughout this book, also address the growing need to integrate stakeholder views and social impacts, in addition to the environmental perspective, into business strategies and organization management.

The CapSEM Model attempts to integrate the different dimensions of systems, and the tools and their contribution to systemic change, thus resulting in an improvement in environmental and sustainability performance. The transition to sustainable societies is considered analogous to growth in both systems- and performance complexity. Before introducing the CapSEM Model, it is helpful to understand the basics of systems thinking in order to better appreciate the way in which the tools have been systemized within it. Systems thinking plays an important role in both the design and content of all chapters in this book.

2.2 Sustainability and Systems Thinking

A system can be described as a set of interrelating parts that perform functions internally, which overcome their individual limitations. Typical systems are industrial systems, ecosystems, product systems and so forth. Within each of these systems, there are sub-systems such as bio-regional systems, communities, or business sectors. The structure of a system defines relatively stable established pathways as a result of continuous interactions between different sectors. The pathways (for example, languages, cultural customs, economical routines, political decisions, and social codes) design particular circumstances specific to that system. They act as *patterns* in relation to *functions* as *actions*. Functions modify the existing structures by constituting new pathways and become established structures in time serving as templates for new action parameters.

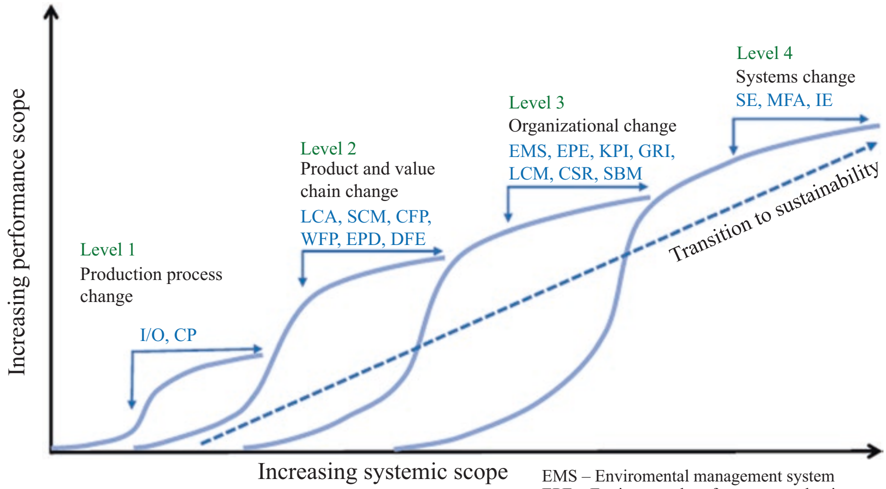
Systems evolve by becoming more complex and more *intelligent*. The most sustainable systems are those which are the most complex and open. Systems, in turn, manage resources. Complex open systems are relatively stable because resources that enter from outside are processed through and assimilated via a function of their complex design, which can be called adaptability. Complex systems are more co-operative than simple ones since they have a wider range and therefore improved opportunities for reacting to changes and possibilities for such reactions. The system then interacts with the other system that provides, for example, new resources, yet still maintains its distinctiveness: it is a new system evolved from its prior form but modified by influence from the outside. Systems changes are also visible at a cultural level, for example, the emergence of industrialization led to massive changes in almost every culture. Some cultures were simply abandoned because of the effects of industrialization. Some appeared to maintain their traditional practices and beliefs within a new context, while others related better to an industrial system and metamorphized into novel, heterogeneous, yet co-operative, structures (Keitsch 2012).

Most sustainability tools apply systems methodologies. A systems methodology can be described as research design based on the transdisciplinary study of the organization of phenomena, independent of their substance, type, or spatial or temporal scale of existence. Systems serve here as templates to investigate both the principles common to complex entities, and the models which can be used to describe them (Heylighen and Joslyn 1995).

Systems methodologies facilitate the comprehension of purposeful relations between heterogeneous performances. Using the reduction of wastewater as an example, a perspective which focuses on a single action would consider the construction of a reprocessing plant for sewage and the recycling of sludge to transform it into a usable by-product, as inefficient, far less direct and more expensive, than simply repairing wastewater tunnels. From a systems methodology perspective, however, the reduction of waste by implementing a recycling system is more efficient, given that it accomplishes many other things, e.g., reprocessing and by-product production, in addition to meeting municipalities' and consumers' needs (Keitsch 2012).

2.3 Capacity Building in Sustainability and Environmental Management Model (CapSEM)

The CapSEM Model can help companies understand their place and the relations of their actions within different levels of related systems. It is presented in Fig. 2.1. A systematic use of the tools in the toolbox helps companies investigate the potential for appropriate actions to change the environmental and sustainability



I/O – Input-output analysis
CP – Cleaner production
LCA – Life cycle assessment
SCM – Supply chain management
CFP – Carbon footprint
WFP – Water footprint
EPD – Environmental product delcaration
DFE – Design for environment

EMS – Enviromental management system
EPE – Enviromental performance evaluation
KPI – Key performance indicator
GRI – Global Reporting Initiative
LCM – Life cycle management
CSR – Corporate social responsibility
SBM – Sustainable business model
SE – Systems engineering
MFA – Material flow analysis
IE – Industrial ecology principles

Fig. 2.1 Capacity building in Sustainability and Environmental Management (CapSEM) Model: a systemic approach towards sustainability. (Modified from Fet and Knudson 2021)

performance related to production processes (Level 1), products and value chains (Level 2) and strategic organizational actions (Level 3). The highest Level (Level 4) represents the larger societal or industrial system and a company's recognition of its place and responsibility within it. The waves in the model illustrate different Levels of performance of the systems under study, and the abbreviations are the acronyms for the different tools placed at the different Levels in the model. The term *change* is used here as meaning the reduction of negative impacts and increase of, or replacement with, positive impacts—ultimately leading to strong, proactive, and holistic sustainability as companies move toward the upper right of the model. As an organization traverses the Levels, knowledge and tools from the previous Levels are used as input to more extensive methods, meaning that each Level, in turn, encompasses the Level(s) below it.

Each axis in Fig. 2.1 describes a change in scope. The horizontal axis shows the scope of systems and begins at the simple production process at Level 1. Furthermore, it extends to the set of processes within the value chain of a product at Level 2. Then, to the organizational level (Level 3), to ingrain sustainability consciousness and commitment into the structural, reporting and organizational routines of the company through the implementation of management systems that use, for example, key performance indicators or certification schemes to help govern the production processes and product value chains at the lower levels. The scope of the systems on Level 4 can be defined as the sector that the organization is a part of, or as wide as a societal system, since all organizations are part of a larger system.

The vertical axis delineates the scope of performance, here meaning the potential for enacting the greatest sustainability impact across environmental and social dimensions. Level 1 focuses on the environmental impacts of material flows, while Level 2 widens its focus to the performance of the entire value chain and all of the processes within it. Furthermore, Level 3 adds aspects to be considered from a strategic level, such as management systems which may guide organizations through a shift to a higher level of sustainability performance over time. Since Level 4 system's scope depends on the context of the operation of the organization, a higher level of performance can be achieved under the holistic recognition of opportunities that come from improving system performance of each of the other systems at the subordinate levels. From a systemic perspective, these different levels of systems could be described as subsystems and system elements of the larger societal system.

2.4 Background to the CapSEM Model

The CapSEM Model has been developed in line with the progression and evolution of sustainability management over the past 30 years. The reader will therefore note both similarities and differences between the initial classification and ordering of tools and methods and should bear in mind the historical and transitory journey being traced.

A simplified classification of environmental performance improvement tools from 1997 across micro-, meso- and macro-levels is illustrated in Table 2.1. There are no stringent boundaries between these levels, and tools placed at one level are also appropriate at other levels. Their grouping, however, helps to communicate the main system scope of each tool.

Table 2.1 Simple classification of tools for environmental performance improvements

Levels	Appropriate tools/guidelines
Societal (macro)	Agenda 21 (1992), Kyoto protocol, policy frame works.
Industrial (meso)	Cleaner Production policies in broad sense, international protocols.
Corporate (meso)	Environmental Management (EM), Environmental Auditing (EA), Environmental Performance Evaluation (EPE), Green House Gas Management (GHGM).
Product (micro/meso)	Cleaner Production related to products, Life Cycle Assessment (LCA), Material, Energy; Toxicity (MET), Material Input per Service unit (MIPS), Life Cycle Costing (LCC), Design for Environment (DfE) Eco-labels, Carbon Footprints and Water Footprints of Products.
Corporate production process (micro)	Cleaner Production processes

2.4.1 Cleaner Production

Understanding the levels of processes, products, organizations and systems necessitates attention to Cleaner Production (CP), an approach that was introduced in the late 1980s in response to the Brundtland Report. In 1989, a working group at the United Nations Environment Programme (UNEP) defined CP as:

> The conceptual and procedural approach to production that demands that all phases of the life-cycle of a product or of a process should be addressed with the objective of prevention or the minimization of short and long-term risk to humans and the environment. A total societal commitment is required for effecting this comprehensive approach to achieving the goal of sustainable societies (Baas et al. 1990).

This definition clearly focuses on the principles of systems thinking and life cycle orientation. It also includes pollution prevention, waste minimization, source reduction, clean technologies and life cycle thinking, areas that refer to forms of preventative action that reduce the fundamental causes of environmental problems. The definition is more precise than earlier concepts of environmental protection such as pollution control, waste management, environmental control and waste disposal, which were attempts to solve environmental problems by reacting to the effects of pollutants, so called 'end-of-pipe solutions.'

The principles of CP can be summarized as *precaution*, *prevention* and i*ntegration*, ranging from the macro to micro scale. These principles require action in three major fields: *policies*, *processes* and *products*, illustrated in Fig. 2.2.

The top box in Fig. 2.2 denotes CP as a *policy* framework. This broad view has led to the integration of strategies and search for technological opportunities for improved environmental performance in all areas of the economy. While opportunities for efficiency improvement may be implemented under existing economic conditions and institutional structures, the considerable potential for CP, in many cases, involves institutional change, economic change and change in consumer behaviour. CP was therefore originally presented as a significant challenge to human society at technical, economic, institutional and societal levels (Jackson 1993).

Prevention requires actions to be taken that influence the potential causes of adverse effects, thereby averting those effects. Such actions do not address the

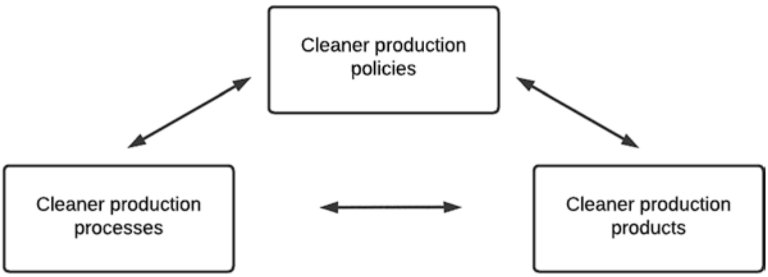


Fig. 2.2 Three major cleaner production action lines. (Fet 1997)

emissions themselves, but the *processes* that cause the emissions, presented in the bottom-left box of Fig. 2.2. Preventative measures are generally process-integrated measures, which attempt either to close material cycles within the process or to substitute hazardous materials used in the process with less hazardous materials. Closed material cycles or replacement of hazardous materials is then further reflected under the cleaner production of *products,* shown in the bottom-right box of Fig. 2.2. Prevention is thus seen to be a dynamic process within a spectrum of possible measures, rather than a specific type.

The CP model in Fig. 2.2 has laid the foundation for the largest set of resulting environmental performance frameworks developed since the cleaner production concept was first introduced in the 1980s. At an organizational level, here indicated mainly by the CP of processes (on the lefthand side in Fig. 2.2), the CP methodology has more or less developed from the guidelines from the United States Environmental Protection Agency's 'Facility Pollution Prevention Guide' (1992). The methodology presents a stepwise guide for establishing a company-wide pollution prevention programme. It outlines procedures for conducting a preliminary assessment by identifying opportunities for waste reduction or elimination. It then describes how to use those results to prioritize areas for a detailed assessment, how to use the detailed assessment to develop pollution prevention options, and finally, how to implement options that withstand feasibility analyses. This has, to a certain extent, contributed to the standardization of environmental management systems (EMS).

The CP of products (right-hand side in Fig. 2.2) addresses not only the production of a product, but also the upstream and downstream activities in the life cycle of the product. To achieve a full understanding of the potential for a cleaner product, a life cycle analysis of the product is required. Life cycle thinking and analysis provide another foundational concept of environmental performance management in the historical development of the CapSEM Model.

2.4.2 Life Cycle Analysis Tools

According to UNEP/SETAC (2005), the main goal of life cycle thinking is to reduce impacts in the resource extraction phase, production and use phase, and recycling phase in the form of emissions from/to the environment by simultaneously improving the social performance at various stages of a product's life. In this way, companies can achieve cleaner products and processes, a competitive advantage in the marketplace, and an improved platform to meet the needs of a changing business climate. A typical life cycle diagram can be found in the UNEP/SETAC Life Cycle Initiative (2007).

The life cycle assessment methodologies of Life Cycle Assessment (LCA), Life Cycle Costing (LCC), Material, Energy and Toxicity (MET) and Material Input per Service Unit (MIPS) are related to products and their life cycle chains including materials, production processes, distribution and disposal. Prior to such methodologies being used, companies that wanted to gain some understanding of key environmental issues linked to their products' value chains often started with simplified material flow analyses like MIPS or MET studies. MIPS was developed in Germany (Liedtke 1994) and set the rules for calculating the material inputs per service unit, also called the MIPS factor which provides an indication of how much material is wasted by each service unit. This laid the foundation for the functional unit thinking inherent in LCA. The MET matrix model was developed in the Netherlands with the idea of focusing on the materials, energy and toxicity of products (Van den Berg et al. 1995). A simple model helps to identify in which of the life cycle phases these aspects have the largest impact and thereby to see where and how to improve the products regarding them. This could be said to be a precursor to the LCA model. The most comprehensive tool for life cycle analyses is the LCA as presented by the International Organization for Standardization 14,040-standards (ISO 2006).

2.4.3 Classifying Improvements in Environmental Performance

In parallel with the classification of the Cleaner Production processes, several attempts to classify a set of principles for improvements in environmental performance appeared in the literature. One approach classifies strategies as shown in Fig. 2.3 (Bras 1996; Fet 1997):

1. Environmental engineering (Bras 1996; Fet 1997)
2. Pollution prevention (United States Enviromental Protection Agency 1992)
3. Environmentally conscious design and manufacturing (Ehrenfeld 1994)
4. Industrial ecology (Graedel and Allenby 1995)
5. Sustainable development (Brundtland 1987)

Area 1 in Fig. 2.3 represents perspectives related to environmental engineering strategies to reduce negative environmental impacts within production and manufacturing processes. This area is concerned with a limited systemic scope in both time and environmental concern (i.e. only during the manufacturing process and life cycle stage).

Area 2 increases the temporal scope and involves pre-planning for the manufacturing phase to prevent pollution and negative impacts during the process. As mentioned previously, pollution prevention strategies arose through the initiatives launched by the US Environmental Protection Agency (1992), with the objective to reduce the environmental impacts of products by identifying them in the design phase. This way, impacts throughout the life cycle could be reduced through better planning at the product design stage. For example, better planning might consider techniques for assembly and material selection to help avoid negative impacts in the use and dismantling phases later in the product's life cycle. So, even though this

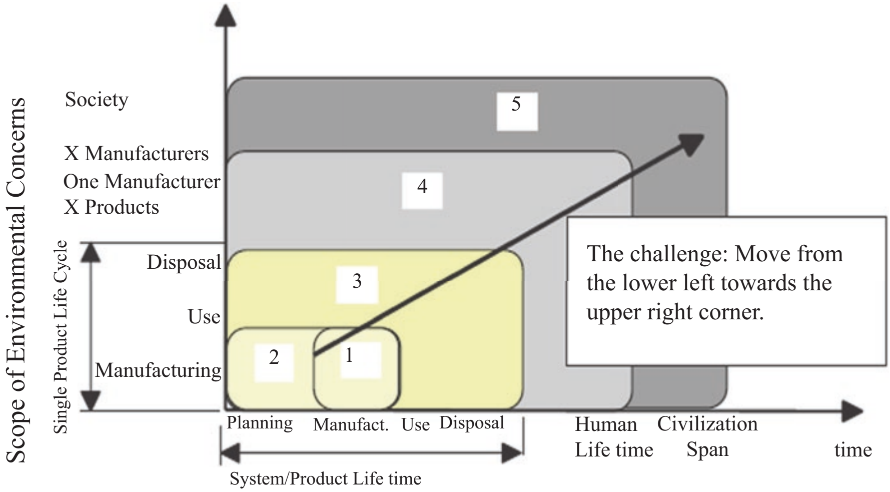


Fig. 2.3 Classification of environmental performance levels. (Modified from Fet et al. 2013)

space only has a limited system scope on planning and manufacturing, it helps build an understanding of potential problems that may arise later in the life cycle. It can be seen as a prelude to the later consideration of the entire life cycle of a product.

Area 3 expands the scope from processes related to manufacturing to the product as a whole and considers design to reduce negative impacts across its complete life cycle. The increase in consciousness of environmental concerns is illustrated through the additional consideration of the use and disposal phases. The wider consciousness is also reflected in the expanding temporal scope related to the gradual knowledge development of how to address the entire life cycle of products (Ehrenfeld 1994).

Area 4 broadens the system boundaries and understanding of impacts throughout the entire industrial system. This includes perspectives related to tracking material and energy flows according to principles of industrial ecology (IE), e.g., industrial symbioses and circular material flow models (Ehrenfeld 1994).

Finally, Area 5 represents the holistic consideration of environmental aspects over an extended timescale and beyond the firm and its network. This means considering aspects relevant for present and future generations and that address all stakeholders, and likely societal and political challenges over time.

To advance Fig. 2.3, a model for a systematic approach to environmental performance improvements was developed over many years (Fet 1997, 2002). Presented in Fig. 2.4, it shows adaptations from the first model, most notably the addition of specific tools and methods for life cycle-based environmental assessment management mapped along environmental performance improvement levels.

Figure 2.4 suggests a series of environmental performance and management tools to be implemented for the purpose of moving to a higher level indicated by Areas 1–5 presented in Fig. 2.3. Readers should note that models presented in

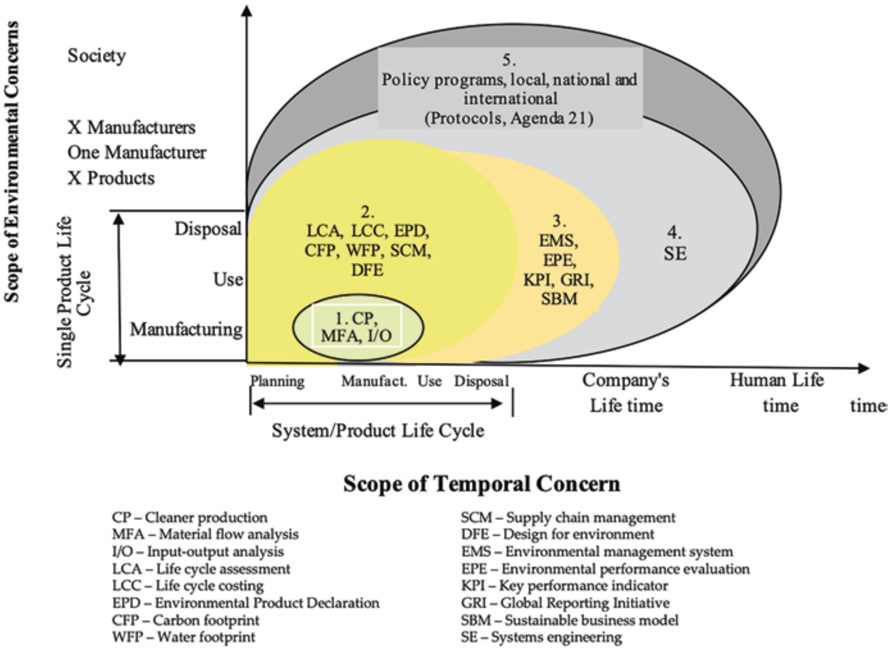


Fig. 2.4 Classification of methods and tools for environmental performance improvements. (Modified from Fet et al. 2013)

Figs. 2.3 and 2.4 focus mainly on environmental aspects of sustainability: they do not fully consider economic and other social aspects.

Figure 2.3, together with Fig. 2.4, are the starting points for the CapSEM Model (presented in Fig. 2.1). Each of the models has advanced the goal to guide companies and other organizations to systematically implement sustainability practices in their products and internal strategies while also building partnerships with the larger societal system.

As seen in Fig. 2.4, Area 1 contains the suggested tools of cleaner production (CP) and input-output analyses (I/O) to monitor the environmental impacts during production and manufacturing processes. In the CapSEM Model (Fig. 2.1), Level 1 encompasses production process-related changes for environmental accounting and (more sustainable) performance (e.g., principles of eco-efficiency (Fet 2003)). When setting objectives related to emissions, resource use and waste generation, companies must assess the current use and flows of materials in order to reduce consumption and waste in their production processes. The I/O method, therefore, fits in Level 1 as it measures baseline Levels for defining improvement and resource efficiency (Bringezu and Moriguchi 2002). Cleaner production (CP) is also located on this level, where source reduction is the objective rather than end-of-pipe solutions (Jackson 1993), thereby moving its placement further along the scales of system scope and performance. The focus on resource efficiency is often driven by economic and/or policy incentives, as these methods provide for diagnostic comparison and benchmarking of companies. Focus only on environmental aspects means that the Level 1 system does not explicitly consider the wider impacts on society. Its system boundaries are drawn at the firm level around specific processes.

In Area 2 in Fig. 2.4, the tools for the purpose of environmentally conscious product development are life cycle assessment (LCA) (Nordic Council of Ministers 1992), life cycle costing (LCC), supply chain management (SCM) (Igarashi et al. 2013), carbon footprint of products (CFP) and water footprint of products (WFP) (Fet and Panthi 2012), environmental product declaration (EPD) (Fet et al. 2009b), and design for environment (DFE). By expanding from the boundaries of a single process, Level 2 in the CapSEM Model focuses on product- and value chain-related changes. This means a focus on a product or service and all activities and processes along its value chain. The methods in Level 2 include LCA, which quantifies material flows (from Level 1) across the full life cycle of a product. Results from an LCA are quantified and weighted in terms of environmental impact. The weighted criteria can then be used to implement changes for more sustainable SCM upstream in the value chain. In addition, the quantified impacts can be used to perform carbon- or water-foot printing of a product, or to reach standardisation for acceptable levels of environmental impact, e.g., EPDs. The principles of DFE, e.g., design for recycling or dismantling, can transform the value chain, accounting, and planning for reduced environmental impact through the full life cycle of the product and its materials. Social-life cycle assessment (S-LCA) could also be placed on Level 2, to track social impacts through the life cycle of a product (Huertas-Valdivia et al. 2020). Such methods are younger in their methodological development and can be difficult to quantify. However, further developing both quantitative and qualitative indicators to measure social sustainability impact is essential to reach holistic sustainability as mandated in the SDGs.

Area 3 in Fig. 2.4 presents tools to be used by companies to improve their strategic approach for being more environmentally conscious, e.g., by implementing environmental management systems (EMS) (Fet and Knudson 2017), environmental performance evaluation (EPE), key performance indicators (KPI), the Global Reporting Initiative (GRI) (Fet et al. 2009a), and business models for sustainability (BMfS) frameworks (Boons and Lüdeke-Freund 2013; Joyce and Paquin 2016). To further increase the comprehensiveness and scope of aspects considered, Area 3 (Fig. 2.4)/ Level 3 (Fig. 2.1) move toward the implementation of methods for stronger sustainability within an organization's management systems and strategy. The transition from Levels 1 and 2 into Level 3 represents an important advancement of management and monitoring for sustainability, allowing the incorporation of more social aspects. The organization must now widen its view beyond the firm itself, or its associated value chains, and track and report on its impacts in relation to the past, to its competitors, and for its long-term survival.

To make and monitor strategic changes across a company's operations, tools and methods for organization-level changes help address more complex sustainability challenges. Meeting these challenges might include establishing management systems to monitor goals for reducing negative environmental impacts and engaging further with stakeholders and customers. It also means looking beyond the value chain for effects of the organization on its employees and global and local environments in the long-term. Level 3 tools, therefore, include EPE, life cycle management (LCM) and EMS for benchmarking, meeting goals and continuous improvement (e.g., through ISO14001). Corporate social responsibility (CSR) embraces the triple bottom line of sustainability and is one approach to stakeholder engagement (Carson et al. 2011; Skaar and Fet 2012). Establishing KPIs is an essential step in setting these goals, and companies can use a range of indicator frameworks from national systems to large, standardized reporting and communication systems such as the GRI. Methods from Levels 1 and 2 can be used to collect the data required for measuring the KPIs: demonstrating the knowledge development path represented by the CapSEM Model. BMfS are also placed on this level as they can help firms conceptualize their current value flows (environmental, economic, and social) and identify areas to innovate for sustainability (Evans et al. 2017).

To achieve sustainable development in the long-term perspective, Areas 4 and 5 in Fig. 2.4 present the policy programmes and international regulations that help to set goals for a larger societal system. The highest level in the CapSEM Model, Level 4 also focuses on systems-related changes. This includes the most comprehensive assessment of sustainability aspects, both environmental and social, and for the company to see itself as one actor in a complex network of actors. While Levels 1–3 focus mainly on environmental aspects, Level 4 (and the higher degrees of the Level 3) command the inclusion of stakeholders and their long-term needs. Here, systems engineering (SE) is suggested as a helpful methodology to address these challenges and includes the principles of industrial ecology, e.g., principles of industrial symbioses and circularity (Sopha et al. 2009). Material flow analysis (MFA) is also placed on this level because it is an analytical model for measuring the material flows in larger systems, e.g. industrial systems together with societal interactions in the bio geosphere (Bringezu and Moriguchi 2002). The acronym MFA has also been used for material flow accounting most often used at manufacturing processes as in Fig. 2.4. In the first version of the CapSEM Model, MFA was on Level 1 (Fet and Knudson 2021). The model was later modified with MFA at Level 4 to indicate that MFA is a broader concept, also covering the economic system and bulk flows through a system, often presented by macroeconomy indicators.

2.5 A Systematic Approach to Using the CapSEM Model

Systems engineering (SE) is introduced as an overall process at Level 4 to better consider stakeholder opinions and involvement in a holistic transition process. SE can be viewed both as a discipline and process (Fet 1997). As a discipline, SE concerns taking the holistic life cycle perspective and bringing in aspects from other disciplines as needed in a multidisciplinary context. SE as a process concerns "bringing a system into being" accompanied by an understanding of challenges to the system during its life cycle (Blanchard et al. 1990).

A six-step SE-methodology introduced suggests the following steps (Fet 1997):

1. Identify stakeholders and their needs related to sustainability performance (of a system, hereunder also an organization or the society as a system).
2. Define requirements for the achievements of stated needs.
3. Specify current performances related to environmental, social and economic aspects.
4. Analyze and optimize performance according to needs and requirements.
5. Suggest solutions according to stated needs and requirements.
6. Verify the suggested solutions against 1. and 2.

These six steps can be used for each area in Fig. 2.1. The complexity of stakeholder involvement and therefore sustainability aspects to be addressed along the development from the lowest to the higher levels, will increase. Thus, an initial step should be to describe the system under study by e.g., a production flow-diagram, a product tree and the supply chain of the product, or the organizational chart of a company. The steps in the SE-process can be undertaken in several cycles until the most sustainable performance has been achieved. For simplicity, SE is placed at Level 4 in the CapSEM Model to illustrate that it yields to the lower levels, but also because the increased scope required for Level 4 represents the most advanced form of SE. The use of SE is elaborated on in Part II Chap. 12.

2.6 Conclusion

The CapSEM Model comprises a spectrum of tools and methodologies for transitioning towards sustainability. It does not mandate that a company place itself within one level. Rather, it shows the way the tools and perspectives are linked and build upon each other. Additionally, it provides an example toolbox of methods that can be applied for improved sustainability in an organization depending on its level of ambition or maturity. The CapSEM Model demonstrates how the different dimensions of systems and tools can be integrated to contribute to increased environmental and sustainability performance. Transitions can be achieved within organizations using the tools presented first in Fig. 2.4 and advanced since the early 1990s.

Numerous scholars have suggested categorizations of environmental performance and sustainability methods (e.g., Robèrt et al. 2002; Singh et al. 2009; Mura et al. 2018). The CapSEM Model, however, classifies analytical methods and tools in a practical way that can serve as an entry- or positioning point for companies. Its development has paralleled the historical growth in concern for the environment and is a result of engagement with companies of various maturity levels and outlooks over the period.

As an organization moves between levels, tensions or limitations may be identified in relation to requirements or assumptions in methods at other levels. This may be due to the limited scope of certain methods that are unable to capture aspects across all SD dimensions. In many cases, tough decisions must be made between sustainability trade-offs and requirements that the organization has a clear strategy to guide their priorities.

Part II of this book describes the tools presented across the CapSEM Model. Part III will test the tools across different sectors and the different dimensions of sustainability. Part IV will analyse usability, feasibility and flexibility of the tools for different stakeholders to encourage development of the model as systematic progress towards stakeholder involvement and actions for checking the achievements of initially formulated needs and requirements. The CapSEM Model needs, for example, to take stakeholders into consideration when specifying accurate level boundaries.

Nevertheless, it has proven to be helpful for business and organizations that struggle to find a systematic approach toward implementing sustainability. No matter what drives this implementation within an organization, sustainability entails complex problems and challenges (e.g., Lang et al. 2012, Schaltegger et al. 2013, Brandt et al. 2013) that require transdisciplinary, collaborative, and holistic thinking across triple-bottom-line principles, long-term systemic reasoning and wide stakeholder engagement. The CapSEM Model is a conceptualization of methods and tools to help companies address these challenges, and to identify their implicit opportunities for sustainable development.

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Chapter 3
Sustainable Development Goals and the CapSEM Model

Annik Magerholm Fet, Haley Knudson, and Martina Keitsch

Abstract This chapter discusses the links between Sustainable Development Goals (SDGs) and the CapSEM Model. It suggests placing these SDGs along the four Levels of the model to serve as a starting point for organizations' engagement with the goals and their objectives. The location of SDGs in the nested system perspective or 'wedding cake model' according to Griggs et al. (Nature 495:305–307, 2013) and later Rockström and Sukhdev (New way of viewing the sustainable development goals and how they are all linked to food. Stockholm Resilience Centre/ Stockholm University, 2016) situates the economic system within the societal system, which is situated within the system of the biosphere and helps to conceptualize the interconnections between SDGs and the dimensions of sustainability. Taking a similar systems thinking approach, the CapSEM Model situates sustainability and environmental management methods and tools within the systems of business operation and production. Extending and merging these two perspectives, the SDGs are placed along the CapSEM Model to provide a point of engagement for organizations to align their activities with SDG objectives.

3.1 Sustainable Development Goals

The 2030 Agenda for Sustainable Development is "a plan of action for people, planet and prosperity" (United Nations 2015). The 17 Sustainable Development Goals (SDGs) (embedded in Fig. 3.1) are the core of the agenda, established to guide the

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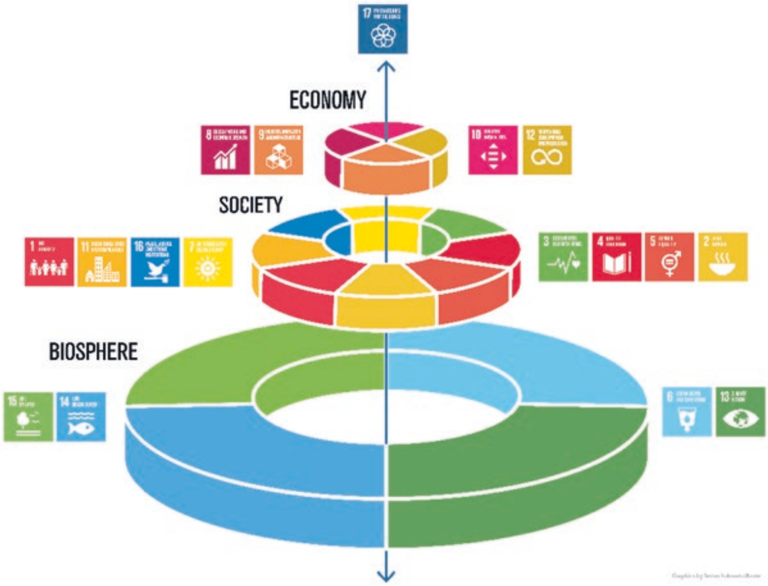

Fig. 3.1 The SDG wedding cake. (Rockström and Sukhdev 2016)

global sustainable development agenda until 2030. The goals recognize that "ending poverty and other deprivations must go hand-in-hand with strategies that improve health and education, reduce inequality, and spur economic growth – all whilst tackling climate change and working to preserve our oceans and forests" (UN Department of Economic and Social Affairs 2022).

The SDGs extend beyond the prior global development framework, the Millennium Development Goals (MDGs), which focused on global poverty reduction. In recognition of the MDGs' constraints, the SDGs were developed, involving stakeholders globally and enhancing the goals with a set of specific targets and indicators for national governments for measuring and communicating progress (United Nations 2017).

Critics of the triple-bottom-line approach, such as Griggs et al. (2013), suggested substituting environmental, social and economic silos with a more unified approach in a nested system for sustainable development. These factors were combined to develop the SDGs into a systemic framework necessitating the recognition of the interconnectedness between the environmental, social and economic dimensions through the goals and their targets. The objectives and requirements for achievement of SD on the system level is represented by the 17 goals and their 169 targets.

Although the official SDG target and indicator framework is aimed at national governments, the success of the agenda hinges on all stakeholders and their engagement and commitment. Crucial to this is the contribution by industry and businesses. Since 2015, a number of companies use SDGs to direct and communicate their sustainability strategies as well as share their results. Several organizations provide guidelines and frameworks for use in companies to set goals and indicators for their respective strategies and operations. The SDG Compass (2015), a joint initiative between the World Business Council for Sustainable Development (WBCSD), UN Global Compact and the Global Reporting Initiative 2015 is a good example. They provide databases of business tools and indicators that give open access to companies. Nevertheless, there are many challenges involved when attempting to follow the 17 goals together with their respective targets and indicators.

3.2 SDGs and the Three Dimensions of Sustainability

The nested model shown in Fig. 3.1 illustrates an embedded view of the three dimensions of sustainability. The economic layer, or system, is nested within the societal layer, which is ultimately nested inside the Earth's biosphere. This communicates the essential fact that all activities must be considered within the Earth system. This model, often referred to as the *wedding-cake model*, maps each SDG along these nested sustainability dimensions, or *layers*. Relationships and interactions between the layers and therefore between the goals, then become apparent. For example, environmental impacts are caused by the interactions between man-made systems (in the societal and economic layers) and nature (the biosphere layer). SDGs 6 (clean water and sanitation), 13 (climate action), 14 (life below water) and 15 (life on land) are those goals directly linked to changes in the natural system caused by the flow of material in and out of its many interacting systems.

SDGs 1 (no poverty), 2 (zero hunger), 3 (good health and well-being), 4 (quality education), 5 (gender quality), 7 (affordable and clean energy, 11 (sustainable cities and communities) and 16 (peace, justice and strong institutions) are associated with the societal layer of Fig. 3.2, as their objectives align with the changes necessary for

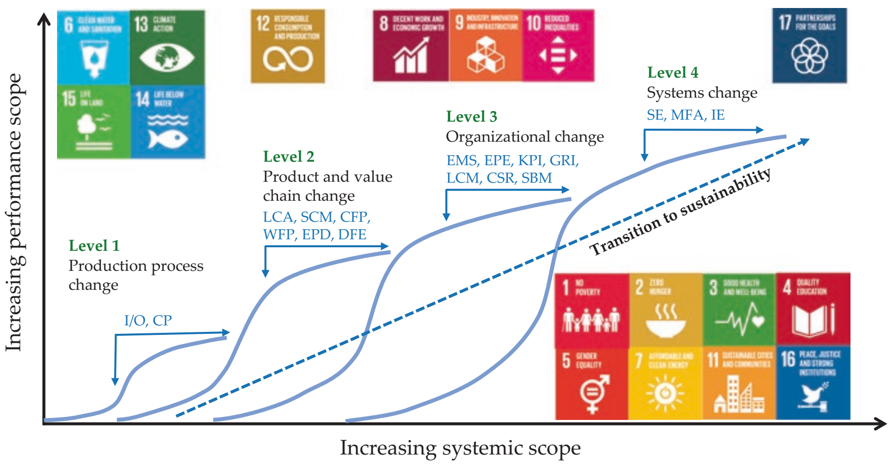

Fig. 3.2 CapSEM model together with sustainable development goals. (Modified from Fet and Knudson 2021)

sustainable development across societal systems. Furthermore, SDGs 8 (decent work and economic growth), 9 (industry, innovation and infrastructure), 10 (reduced inequalities) and 12 (responsible consumption and production) are placed along the corporate layer because their objectives require shifts in business strategies to achieve sustainable solutions. Finally, SDG 17 (partnerships for the goals) is seen as a requirement for, and outcome of, the entirety of the goals. This model is valuable in the process of conceptualizing, distributing and systematizing efforts to move towards achieving individual SDGs.

3.3 SDGs and the CapSEM Model

Rockström and Sukhdev's (2016) wedding-cake model places SDGs along layers of the interacting systems of global sustainable development: biosphere, society and economy. Comprised of a similar systems thinking approach, the CapSEM Model places tools and methods for measuring environmental and social performance along the interacting systems of business operations and production: production processes, the product value chains, the organizational operations and larger systems activities. Figure 3.2 therefore introduces an analytical model that places SDGs along the four Levels of the CapSEM Model. This is intended to help organizations distribute and systematize their work toward SDGs by assisting their understanding of how their activities affect and contribute to each of the goals. The advantage of comparing the CapSEM Model with the SDG model in Fig. 3.2 is that while Fig. 3.1 locates the SDGs hierarchically within the three spheres of sustainability, Fig. 3.2 illustrates (and facilitates) dynamic movement and iteration between different systems levels of applications in the transition towards sustainability.

Although the goals are each placed on a single level of the model, this is used primarily to illustrate an entry point to their application. In reality (and inherent to their conceptualization as a framework), the SDGs overlap and transgress. Their placement on specific levels in Fig. 3.2 therefore indicates an emphasis on certain areas, but does not lock them in or prevent their being considered in other areas. Given their systemic nature, each SDG will expand and interact over several areas. However, in order to incorporate the SDGs into business strategies, specific goals and targets must be indicated and prioritized as a starting point.

SDGs 6, 13, 14 and 15 reflect impacts on the biosphere and are placed on that level in Fig. 3.1. This thinking is also applied in Fig. 3.2. The *biosphere SDGs* are placed on Level 1 since material flows in and out of a system, impact different systems of the biosphere, such as land, sea or air. In the CapSEM Model, these flows are monitored within Level 1, where energy and material flows are measured by tracking their movement in and out of the man-made systems under study, referred to as production processes. Material flows in and out of the systems under study also occur within Levels 2–4 of the CapSEM Model and are based on the same calculations and principles as Level 1. Rather than specific production processes (Level 1), the respective processes are summarized as the systems of the product value chain (Level 2), the organization's production site and impacts related to strategic decisions through stakeholder involvement (Level 3) or the societal well-being or sustainability at a regional or national Level (Level 4).

Similar impacts are likely to occur on the other Levels in the CapSEM Model, but this is then as a result of the material flows described under Level 1.

SDGs 12, 8, 9 and 10 reflect impact on the economy and are placed on that level in Fig. 3.1. However, these SDGs are placed on Levels 2 and 3 of the CapSEM Model. SDG 12, for example, concerns responsible consumption and production. This reflects the activities upstream and downstream in the value chain of products (Level 2). The achievement of this goal is also dependent upon strategic choices made in the producing organization (Level 3), and on the behavior and needs of people in society, Level 4 of the CapSEM Model.

The rest of the SDGs are grouped on the *societal* level in Fig. 3.1. These are not placed at one specific level of the CapSEM Model, but rather shown as goals that should be used as contextually appropriate for driving an organization's transition to sustainability. The use of these goals should therefore be considered according to the specific sector being studied or problem analysed. An example of this is SDG 7 as the role which affordable and clean renewable energy will play and important contribution to changes towards sustainable solutions on all levels.

SDG 17 is placed on the top of the *wedding cake* in Fig. 3.1, and similarly in the CapSEM Model as a goal to be focused on during the entirety of the transition process.

3.4 Conclusion

The models assigning SDGs as shown in Figs. 3.1 and 3.2 are not so very different. They both structure SDGs according to their role in the transition to sustainability. However, the additional value provided by their placement in the CapSEM Model is the toolbox of methods and tools suggested for use by companies and other organisations in this transition. The CapSEM Model helps make sense of the many methods available for tracking, measuring and improving sustainability performance by grouping them by level. By grouping the tools by level, it may be easier for companies to consider using them, and to identify which tools are useful for addressing environmental, economic and social impacts associated with each of their activities and processes. This chapter has expanded the systematized approach to the inclusion of the SDGs and their placement along the four levels of the CapSEM Model. The model presented in Fig. 3.2 is an analytical representation of one approach to engaging with the SDGs. Each of the goals is placed along one level to serve as an entry point to understanding the activities and interactions that affect that goal's objectives. Their placement on one level does not mean that they are not relevant on other levels. However, when working with companies, often overwhelmed by their growing sustainability requirements and limited existing capacity, modest models that help simplify complex objectives can serve as a baseline for engagement and improvements in sustainability. The combination of the CapSEM Model and SDGs therefore takes this approach.

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Part II
The Toolbox: Methodologies and Theories

Chapter 4
Input-Output Analysis and Cleaner Production

Annik Magerholm Fet, Cecilia Haskins, and Magnus Sparrevik

Abstract This chapter gives an overview of the basic principles for analysing material flows for production processes. This type of analysis is based on a calculation of materials going in and out of a process. Typical materials to be accounted for are energy, raw materials and other supporting materials. Likewise, outputs from a production process are waste of different types, emissions to air, water and soil, as well as noise, radiation, vibrations, and loss of heat. In an input-output analysis, the by-products from the process are also accounted for. The chapter also explains the principles of cleaner production starting with the motivation from corporate leadership to make production processes cleaner: to reduce waste and emissions and use material in a more efficient way. The concept of Cleaner Production (CP) also embraces strategic changes for making production and products cleaner and greener. However, the purpose of the chapter to provide information about basic principles for collecting information to be used in an environmental account for organisations, which will help them improve their overall environmental performance.

4.1 Introduction

The cleaner production methodology described in this chapter is based on an understanding and accounting of material and energy flows into a production process, the emissions, discharges and waste streams generated in the process and the by-products and final products (or service) that come out of the process. For the

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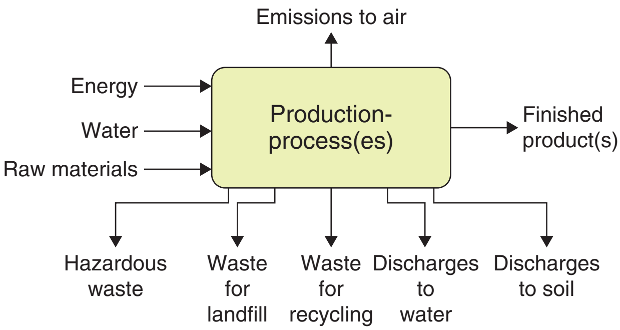

Fig. 4.1 Material flow scheme with inputs & outputs for single/series of production process(es)

purposes of this book, it is referred to as an input-output (I/O) analysis throughout. Typical inputs are materials (e.g. processed, recycled, reused or raw materials; natural resources), energy and services. Outputs are products (e.g., main products, by-products, recycled and reused materials), services, wastes (e.g., solid, liquid, hazardous, non-hazardous, recyclable, reusable), and emissions (e.g., emissions to air, effluents to water or land, noise, vibration, heat, radiation, light). A visual representation of these inputs and outputs is presented in a material flow scheme, see Fig. 4.1.

The operations of an organization may be logically grouped based on inputs to, and outputs from, their different physical facilities and equipment. Operations also include the supply to, and delivery from, them. This can be illustrated by a process flow diagram for the production site, such as the one which Pingmuanglek et al. (2017) produced for starch production.

I/O Indicators can further help to account and compile the inputs and outputs of the material streams of the process, form the basis for assessment of subsequent improvements and are often used to communicate quantitative information. The set of I/O-indicators are often referred to as the firm-level operational performance indicators (OPIs) (ISO 2021). A summary of material flows for each of the processes in a production, or the aggregated OPI-values, will then form the environmental account of the entire production site. OPIs are important when a company establishes its environmental aspects, goals and programmes for environmental improvements. It will show change in the environmental performances over time and is an essential part of the environmental management system of the company (see Chap. 7). An environmental account is also of great importance in providing the underlying information for cleaner production.

4.2 Defining Cleaner Production Strategies

Cleaner production (CP) comprises strategies that aim at reducing environmental impacts and impacts on health and safety resulting from products throughout their life cycle, from the extraction of raw materials to their elimination. It encompasses concepts to minimise waste production; eco-efficiency; pollution prevention or green productivity. CP is relevant for companies with large quantities of emissions and waste, no overview of resource usage, material flows and waste generation, and high consumption of water, energy and other inputs. According to the action lines presented in Fig. 2.3 in Part I, Chap. 2, CP-principles can be summarized as precaution, prevention and integration, ranging from the macro to micro scale of policies, processes, and products. Prevention refers to proactive actions on the corporate operational level aimed at the causes of pollution. Rather than addressing emissions after they are released, the actions aim at the heart of the cause of these emissions. The measures may attempt to either close material cycles inside the industrial process or substitute hazardous materials with less hazardous ones. Prevention is a dynamic process within a spectrum of possible measures rather than a specific type of measure, focused on industrial processes that include considerations of both products and the nature of consumer demand (Jackson 1993).

4.3 Performing a Cleaner Production Project

CP implies a change of focus from the usual question of “How can we handle our waste and emissions?” to a more proactive set of questions, such as “Where do waste and emissions come from, how can they be avoided, and if unavoidable what other options are available?” An illustration of cleaner production strategies is given in Fig. 4.2. Emphasis when employing these strategies should ideally focus on *the left* branch of this hierarchy and only consider *the right* branch when all possible alternatives have been exhausted.

CP initiatives can be implemented by following the 5-step plan recommended by the US Environmental Protection Agency (USEPA 1992) as follows Sects. 4.3.1–4.3.5. This model has later been slightly revised by Baas (1995), and by Zhang et al. (2018), however the main approach follows a set of similar steps.

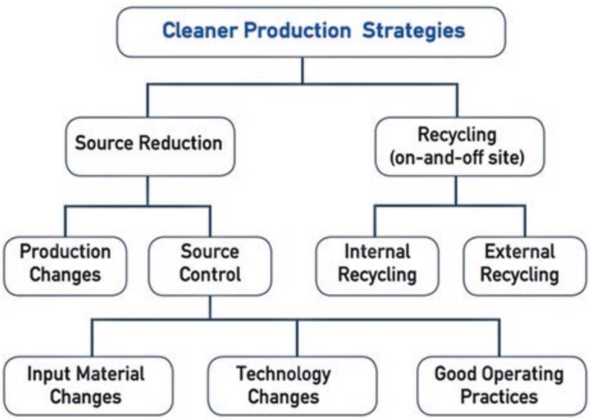

Fig. 4.2 Illustration of the principle for CP strategies (USEPA 1992)

4.3.1 Planning and Organisation

CP strategies suggest a variety of measures that contribute to reducing waste and pollution at source. After gaining management commitment for conducting a CP assessment (CPA), a specific issue, or set of issues, should be agreed upon as the target of the assessment project. A qualified team of assessors should be identified and organised as a task force to address the preparations and inspections needed.

4.3.2 Preparation

As an integral part of implementing CP, companies need to build their environmental account. An environmental account includes mapping of all material flows and an assessment of the impact on the environment caused by these flows, together with an environmental impact assessment of products and services. Essential to the preparation phase, is the collection and classification of available and relevant data and other corporate records regarding the assessment target(s). As options for improvement are identified, the activities will enter a feasibility analysis phase, as illustrated in Fig. 4.2.

4.3.3 Assessment Step

There are a wide range of methods available for generating ideas for CP improvements. Workshops and brainstorming sessions may be used. Methods for CPA may in addition include table-top exercises, checklists and inspections on site. All methods should ensure that participation is encouraged, that ideas are documented and that all ideas are given appropriate level of consideration.

4.3.4 Feasibility Analysis Step

Based on information gathered through the assessment phase, the different options are analysed to determine whether implementation of the options can be justified. Three types of feasibility studies are usually made before selecting an option for implementation.

- Technical evaluation (Is it technically executable with regards to the set demands?)
- Economic evaluation (Is it financially justifiable?)
- Environmental evaluation (Will it provide a satisfactory environmental solution?)

Technical Evaluation

The technical feasibility of proposed options must answer the question, "Will the suggestion reduce pollution and waste in the given situation?". Any proposed adjustments to the production facilities should consider physical obstacles to the actual construction as well as the potential impact on the specific requirements of the product. Of special interest are: the market availability of the required equipment; the commercial availability of proposed equipment; and the maturity, i.e., has the equipment been demonstrated and tested successfully and used in similar conditions? Questions related to availability and suitability are the primary concern of a technical evaluation for any promising option for pollution and waste reduction.

Economic Evaluation

Standard measures of financial return on any planned investments are used during the economic evaluation. This includes tools for analysing and comparing economic consequences of potential investments, such as pay-back on investment, internal rate of return, and net present value.

The simplest way to determine if a project is a good investment is to add all the savings and deduct the sum of all the expenses. Savings and expenses may be hidden in company accounts under different headings. As an example, the cost of waste disposal may be directly available in the accounts, however it is unlikely to specify in detail which materials are wasted and in what quantity. In addition, accounting for any lost labour, and production downtime, can be challenging. Certain costs may also be recorded as fixed, even they are variable. A valuable method for assessing costs and savings is conducted by holding thorough discussions with the responsible accountant together with staff from different parts of the operations and management. This might include a walk through the premises, which may reveal that certain expenses or savings are not included in the accounting, such as so-called overhead expenses. However, the team should focus on the main areas in order not to waste too much time on details and small amounts. It is also possible, that companies can reduce their overall risk, through the introduction of cleaner production measures which can have a positive influence on the economic evaluation.

Environmental Evaluation

Data collected in previous phases is applied to the analysis of internal and natural environments. The internal or working environment can have environmental effects on workers. A poor internal environment can manifest in a high absence rate and lower productivity in production. The natural environment encompasses the surrounding areas of the company, consisting of soil, air and water. Pollution of the natural environment affects the local community and can also have global consequences. This analysis requires knowledge about how the various production processes impact the natural environment. Benchmarks with regards to quantitative OPIs before and after a production change, a material change, a technology change or an operational change, become evidence for the objectives achieved.

4.3.5 Implementation

In this phase, the selected options are delivered according to the recommendations and plan of action in the final feasibility study. It is also noteworthy that this process is highly iterative. If the technical feasibility is incomplete, it may be necessary during this phase to revisit the earlier assessment phases before proceeding. As the company gradually identifies new targets for CPA, the overall benefits of CP and return on investments are realised.

When the company has completed a CPA in one part of the production line, the organisation has obtained the competence to use this experience in other parts of its operations. It can be challenging to prioritise improvement options resulting from a CP. It is obvious that options with high environmental benefit, low technical problems and high profitability should be considered first. Normal housekeeping measures will be at the top of the list and can usually be implemented immediately. Other criteria for prioritizing candidate options include the following:

- Comply with all existing environmental demands from regulatory agencies
- Evaluate demands from neighbours, insurance companies, banks and customers
- Avoid use of toxic substances whenever alternatives exist
- Reduce total consumption of materials and energy
- Continuously consider methods for closing material streams internally
- Investigate ways in which company waste can become a resource for others by establishing an industrial symbiosis

It is important that environmental concerns are prioritised before short term financial gains, and that environmental measures are compatible with long term investments, project plans and product improvements.

Plan of Action

Before moving on from this phase, the team should propose a plan of action that prioritizes and addresses execution of the most promising options. The plan of action should include a list of activities needed for the implementation and measurements, design, contact with the equipment providers, and other resource requirements. Some of the options may require competence outside the company, in which case, consultancy support should be considered. The plan of action should also consider if some of the options should be implemented as demonstration projects and whether it is possible to receive financial support to conduct such pilot projects. The execution of a demonstration project should also be described in the plan of action.

Additional Uses of the Feasibility Analysis Report

A completed feasibility analysis is useful for the company in many ways. The company benefits from an overview of the material flow in the surveyed work process; an overview of waste and emission streams, and which technical, economic and environmental challenges are connected to candidate measures for improving the natural and internal environment. A thorough report from the feasibility analysis phase provide auxiliary benefits beyond the initial purpose. Many governments demand a technical environmental analysis when issuing permits for emissions, and a good report can support this. In connection with increased demands on companies to provide environmental reporting documentation, a complete report from a CPA provides a good starting point. The report also provides a strong foundation for registering environmental improvements after completion of the initial study.

4.4 Conclusion

CP is a broad concept with implications for application at all levels of society. This chapter has mainly focused on CP processes. CP strategies can be adopted by individual companies, by a cluster of industrial enterprises, at regional and state levels of government and at a global level through treaties and international agencies. Indications are that compliance with CP principles of waste and emission avoidance and reduction render positive results for all three pillars of sustainable development – social, environmental, and economic. There remains a need for a consolidated strategy that combines the many different instruments for promoting collaboration in the direction of CP by bringing together all relevant stakeholders.

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Chapter 5
Looking Beyond the Factory Gates: Life Cycle Assessment, Supply Chain Management and Design for Environment

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Abstract This chapter gives an overview of the principles of life cycle assessment (LCA), supply chain management (SCM) and design for the environment (DfE). They are all placed at Level 2 in the CapSEM Model as tools for enhancing the product by improving the actual production processes that take place at different stages and subsystems in the life cycle of a product. One way of analysing and ameliorating the environmental performance of a product can be by analysing the environmental aspects and impacts initially by performing a life cycle assessment aimed at finding the most significant environmental impacts in the life cycle of the product. These hotspots can then be identified under different suppliers in the upstream value chain. Results from this analysis should then be addressed in the design of a new product, and further result in changes to the supply chain by supply chain management. An optimal solution for improving the environmental impacts at the different stages of the life cycle of a product, can be achieved at the end by introducing this into design principles as better specification of the performance at each stage in the life cycle of the product. This chapter also introduces green public procurement as a driver for change in the supply chain.

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5.1 Introduction

Since the introduction of cleaner production (CP) programmes in the early 1990s, the focus has gradually expanded to include activities outside factory production sites. Businesses became more aware of their responsibilities during the entire value chains of their products, both upstream and downstream. The CapSEM Model suggests tools for analysing and evaluating impacts of products and activities in a life cycle perspective along value chains. This chapter gives a general introduction to life cycle assessment tools, including the standardized Life Cycle Assessment (LCA) to consider the product system, Supply Chain Management (SCM) to manage the value chains of suppliers and products, and design for environment (DfE) to integrate environmental concerns in the development of products and services.

5.2 Life Cycle Analyses Tools

A life cycle assessment takes the entire life cycle of a product into consideration, i.e., the *cradle to grave approach* (Hauschild 2018; Owens 1996). Life cycle assessment methodologies, LCA, Life Cycle Costing (LCC), and Material Input per Service unite (MIPS), are related to products and their life cycle chains, materials, production processes, distribution, and disposal with the most comprehensive tool being the LCA (Ness et al. 2007). Performing a complete LCA for a product consisting of a high number of components, is very time-consuming. Companies may not want to perform a complete LCA, but rather want to obtain an overall impression of key environmental issues linked to the product value chain. Simplified analyses such as Life Cycle Screening (LCS) or Material, Energy and Toxicity (MET) studies may be used for this. When environmental life cycle analyses are combined with LCC-analyses, they are appropriate for decision support or strategic planning related to both product and process improvements.

5.2.1 Environmental Life Cycle Assessment

In order to consider a product's specific environmental aspects, the most extensive method available is LCA methodology. LCA methodology was first developed in Switzerland in the 1960s and further developed by the Society of Environmental Toxicology and Chemistry (SETAC). It became standardized as an international standard in 1996 and is included in the ISO 14000-family of environmental management standards (ISO 2006a, b). During the 1990s, many studies reported omissions and weaknesses within the methodology (Lindfors et al. 1995; van den Berg et al. 1995). Although the standards have been in use for many years, debate remains around the accuracy and relevance of the results of an LCA (Ross et al. 2002; Owens 1996). LCA methodology includes the steps *goal and scope definition*, *inventory analysis*, *impact assessment* and *interpretation* (ISO 2006a). These steps are still identical, but details under each step have evolved over the years and the entire process is well documented in the literature (Hauschild 2018). The direct applications of an LCA is for product development and improvement, strategic planning, marketing and public policy making.

The results of the inventory analysis comprise a list of all raw material consumption, and emissions identified in every process of the entire life cycle are known as the inventory table. This information is usually presented in process flow-charts and used by companies to present an overview of the product system and subsystems (or modules). This overview of quantitative information is further used to analyse and assess the impacts of the environmental burdens identified in the inventory analysis. There is no commonly accepted methodology for consistently and accurately associating inventory data with specific environmental impacts. It is also problematic to find weighting factors which can be adopted globally, due to environmental conditions are under changes as a result of climate changes and pollution in the ocean, for example. Nevertheless, a process impact assessment includes classification, characterization, and valuation. The main purpose of this classification is to briefly describe which potential environmental impacts are caused by the inputs and outputs. During classification, the different parameters from the inventory table are noted under the relevant impact categories. For example, all emissions contributing to global warming are noted under the heading 'Global warming'. The characterization is a quantitative step in which the relative contributions of each input and output to its assigned impact categories are assessed, and the contributions are aggregated within the impact categories. In the valuation, the relative importance of different environmental impacts are weighed against each other. Results from the valuation normally form the basis for environmental improvement priorities. During this stage, different environmental impacts can be weighed and totalled to form an environmental index. An indication is thus available on how one effect can be compared to another.

For the purpose of improving a product, this information is of importance for its design. The findings may also form recommendations to decision-makers in the supply chain.

5.2.2 Life Cycle Screening Tools

Life cycle screening tools were developed to support the development of routines for performing an LCA. When the intention is to identify key issues for further investigations, e.g., identify parts of a life cycle that needs further research, Life Cycle Screening (LCS) is recommended (Heijungs 1996). LCS is a simplification of an LCA, however it can never claim to be a substitute for a full LCA (Bovea and Pérez-Belis 2012; Suppipat et al. 2021). The name *MET matrix* is derived from the first letter of the LCS categories, i.e., Material cycle, Energy consumption and Toxic emissions (Brezet and van Hemel 1997). The MET-matrix is a tool for quickly identifying a product's main environmental aspects (Stefanov 2017). It is a simple input-output model combined with the product's life cycle. The nature and the volume of raw materials used in the product are considered, as well as the energy it requires and the waste and emissions it generates. This requires reflection on the product's entire life cycle, from the extraction of raw materials up to and including processing the product after it has been disposed. Three categories of environmental aspects are distinguished in this input-output model as follows:

- Material cycle: raw materials - materials - waste (a line that should be transformed into a cycle)
- Energy consumption: energy consumed during the various stages of the product
- Toxic emissions: hazardous emissions to water, soil, and air

Material Input Per Service unit (MIPS) is another tool developed in 1990s. The MIPS concept is a life cycle tool for analysing material inputs per service unit. It measures ecological impact, showing the same system boundaries for all examined services. Services imply utilization that could be obtained from a product (or infrastructure) to satisfy human needs and desires. In this concept, the product is conceived as the *service delivery machine*, or *service machines*, focusing on the use of resources and less on waste streams. By calculating material and energy flows and the number of products produced, the material intensity related to the function of that product can be calculated, thereby creating a picture of the environmental performance related to that product. The concept is based on the philosophy that better utilization of materials and resources is needed to achieve a sustainable development (Liedtke 1994; Robèrt et al. 2002).

A direct comparison of the MIPS between products that differ in their consistency is significant in cases of functionally equal products. The definition of the service unit is therefore important. The calculations start with a screening phase where the product's material intensity measure is calculated based on inputs alone. It is not necessary to count waste outputs, which would result in double counting, because waste is the difference between material inputs and products (or service) outputs. After the first screening, all known eco-toxicities of the material flows associated with goods or services are carefully considered. The counting of material intensity or resource productivity, the inverse of material input per service unit, 1/MIPS, is referred to as Material Intensity Analysis (MIA). With MIA it is possible to compare the ecological impact intensity of functionally equal substituents (Liedtke et al. 2014). This concept has become an integrated part of LCA as all material flows should be referenced to the functional unit of the analysed product together with its supply chain.

5.2.3 Life Cycle Costing (LCC)

Economic issues drive many decisions in industry, and the results from an LCA-study can be linked to LCC information (Asiedu and Gu 1998). Traditionally cost effectiveness implies *most performance for least cost*. LCC is a comprehensive life cycle approach especially designed for capturing economically related issues with a focus on costs and revenues - not environmental issues (Norris 2001). It involves the collection and sometime estimation of all costs associated with the activities planned and/or accomplished throughout the system life cycle. This includes the costs of research and development, design, production/construction, operation, maintenance and support, and system retirement (Blanchard 1990). Another cost examination instrument is the Value-Added Analysis (VAA), which is related to the MIPS-concept (Azapagic and Perdan 2000). VAA supports an evaluation of the marketability of an eco-efficient product. A comparison between different production technologies or substituents based on both MIA and VAA provides an estimate of where in the life cycle of products and services a low ecological impact can be reached.

5.3 Supply Chain Management

The life cycle perspective makes SCM highly relevant for addressing improvement in sustainability. Whilst SCM originally did not initially focus on sustainability, the inherent, underlying systemic similarities between SCM and LCA suggests that SCM can serve as an important driver and enabler of improving overall sustainability and further encourage the adaptation of approaches such as LCA and LCC (Blass and Corbett 2018).

5.3.1 What is Supply Chain Management?

SCM as a managerial concept emerged during the late 1980s from the field of logistics management, extending the key principles of logistics to a higher system level covering a focal firm's upstream suppliers and downstream customers. Christopher (2016) defines logistics as:

> ...the process of strategically managing the procurement, movement and storage of materials, parts and finished inventory (and the related information flows) through the organization and its marketing channels in such a way that current and future profitability are maximized through the cost-effective fulfilment of orders.

SCM can then be thought of as logistics management across multiple, serially connected actors, i.e. the supply chain. Christopher's (2016) definition of SCM is used widely:

> The management of upstream and downstream relationships with suppliers and customers to deliver superior customer value at less cost to the supply chain as a whole.

The interorganizational dimension of SCM brings with it specific challenges. Coyle et al. (2003) identify several mutually related, areas of attention in SCM, including inventory management, a concern for minimizing the final cost for the final customer, accurate and fast information exchange between upstream and downstream actors, developing relationships and forms of collaborative planning with these actors and addressing the perceived division of risks and gains. The increasing focus on circularity in supply chains further adds to the importance and complexity of addressing these areas of attention (De Angelis et al. 2018). For example, a shift towards circular supply chains is likely to change the interaction patterns, material flows and types of value exchange between various actors, including information flows, the location and types of inventories held, the need for collaboration and planning, and novel business models (along with the implications of these models for sharing risks and rewards).

5.3.2 Why is SCM Important for Sustainability?

When considering the previous section on LCA through the lens of SCM, one could argue that a *life cycle* (LC) perspective coincides with, and implies, a *supply chain* perspective. After all, assessing costs as well as environmental impacts related to the development, production, in-service and dismantling of a product will likely correspond to different stages in a supply chain, i.e., producers of components, producers designing and assembling complete products, wholesalers and distributors of products, final users and service providers. Just as the service level and cost performance offered to the final customer is the sum of the contributions of all supply chain actors involved, so is the environmental impact. Since the first decade of the 2000s, increasing attention has been paid to unravelling SCMs potential as a driver for sustainability, resulting in the body of literature known as Sustainable Supply Chain Management (SSCM), defined by Carter and Rogers (2008) as:

> … the strategic, transparent integration and achievement of an organization's social, environmental, and economic goals in the systemic coordination of key interorganizational business processes for improving the long-term economic performance of the individual company and its supply chains.

In their framework, SSCM builds on four key dimensions:

1. sustainability as an integrated aspect in overall firm strategy
2. risk management, including contingency planning and audits
3. ingraining sustainability in the firm's culture and values and
4. creating transparency, by stakeholder engagement and other measures.

LCA and related approaches clearly support several of these dimensions, most notably carrying out risk assessment and creating transparency. As part of their concept of Shared Value Creation (SVC), Porter and Kramer (2011) identify redefining the activities in the value chain as a key strategy for linking economic value creation to social and environmental value creation, pointing to logistics and purchasing as important areas of attention. Achieving SVC will typically require collaboration across upstream and downstream supply chain actors (as well as other actors in the wider ecosystem) and as Porter and Kramer (2011) indicate: '…successful collaboration will be data driven, clearly linked to defined outcomes, well connected to the goals of all stakeholders, and tracked with clear metrics.' By aligning LCA with supply chain management, a change towards green supplier selection (GSS) takes place. A strengthened focus on environmental responsibility strategies motivates a growing tendency to integrate LCA-based information. Igarashi et al. (2013) indicated how LCA plays an important role in contributing to greener supplier selection. As suggested in their analysis, the use of LCA needs to be aligned with both a focal organization's overall strategy as well as the supply chain context. The use of LCA should be considered in the various stages of the GSS.

In addition, the outcomes of assessing the alignment of the overall strategy with the supplier selection processes will probably also have consequences for how various steps in the green supplier selection process are carried out and how the supply chain context is mapped. Building further on Igarashi's work, Jenssen and De Boer (2019) more specifically identified suitable application strategies for LCA in GSS.

5.4 Design for the Environment

Alongside SCM, Design for Environment (DfE) signifies another important progeny from LCA in the transition towards sustainability. DfE has evolved as practical approach to design products and services thereby meeting environmental challenges identified in LCA.

5.4.1 Background

In 1989, the United Nations Environment Programme (UNEP) began work on approaches for preventing pollution. The resulting strategy, *Cleaner Production*, is an essential part of the Sustainable Production and Consumption Policy (Clark 2007). Since the early 1990s, producers and designers from various industries started to work with cleaner production strategies and to pay attention to the reduction of negative impacts along the life cycle of a product – from extraction of its raw materials to its ultimate disposal. Simultaneously, the Design for the Environment (DfE) approach emerged as a non-regulatory aid for companies to consider sustainability effects when designing and manufacturing commercial products and processes (Ehrenfeld and Lenox 1997). In addition to incorporating environmental concerns into product and service solutions, DfE evolved out of product life cycle assessment (DeMendonça and Baxter 2001). DfE has had an impact on different types of production and manufacturing. It has been part of the Xerox industrial design since 1990, when the company started a 5-year effort to create waste-free factories including 90% minimum reduction in solid waste to landfills, air emissions, hazardous waste, and process wastewater discharges (Azar et al. 1995). DfE has also influenced companies such as Philips and the ICT branch (Mottonen et al. 2010).

5.4.2 Methods for DfE

DfE enables designers to consider traditional design issues around cost, quality, manufacturing process and efficiency as part of a unified decision system (Zheng et al. 2019; Anderson 1995). Using DfE encourages developers to apply LCA to all potential environmental implications of a product or a service being designed, including energy and materials used, manufacture and packaging, transportation, consumer use, reuse or recycling and disposal. DfE tools enable consideration of these implications at every step of the design process (Eagan and Pferdehirt 1998; Bras 1997). The Dutch PROMISE approach (Brezet et al. 1994) is an early DfE approach, which aims to assist business in setting up systematic environmental product development. Tools such as the MET matrix and LCA are recommended in the search for the most important environmental criteria in the product life cycle. Another useful tool for monitoring DfE impacts is the Ecodesign strategy wheel, which comprises seven design strategies for environmental product development. By using a simple grading, poor – average – good, it is possible to map the performance of initial, improved and new products, and then compare their environmental performance against each other. During the 1990s, DfE and the emerging ecodesign concept consisted mainly of quantitative and empirical methods, and subsequent improvement strategies concentrated on the material and energy flows within a system of producers and consumers, aiming to build knowledge about how these flows can be fed into design processes to improve products and production routines (Keitsch 2015). DfE and ecodesign facilitate navigation through the complexity of industrial and natural ecosystems within which societies and businesses operate (Bras 1997).

Brezet and van Hemel (1997) came up with an Ecodesign Strategy Wheel, which is often referred to and in common usage. It illustrates the ways in which product development can be aligned with SCM, DfE and ecodesign. The product development process consists of the following stages: strategy, product planning, need identification, research, analysis, idea generation, concept detailing, customization, marketing. The stages are unexchangeable, however iterations are often made in idea generation, concept detailing, and at customization stages. When designing environmentally sound products, aspects of LCA, DfE and SCM should be integrated at the product planning stage and permeate the whole product development process (Fig. 5.1).

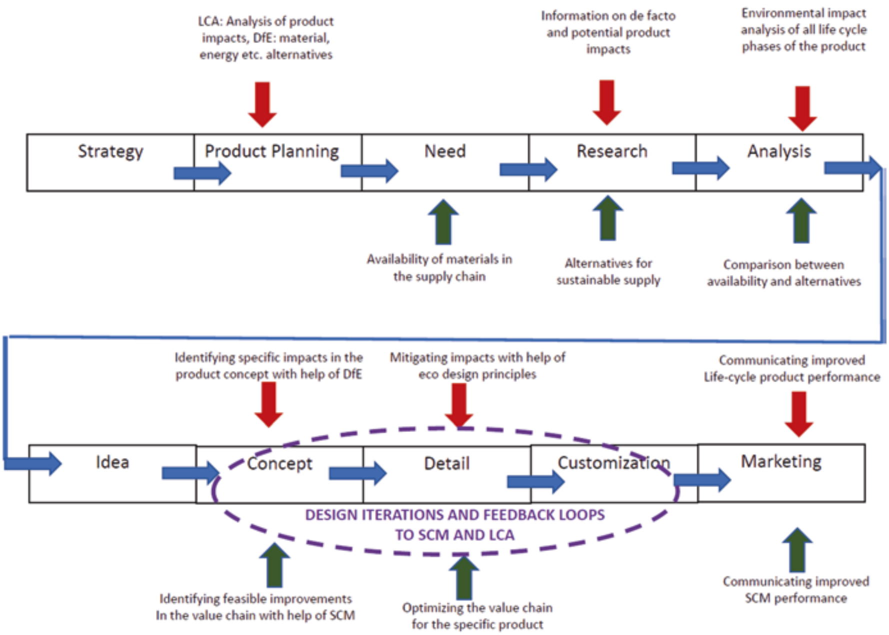

Fig. 5.1 Product development stages integrating aspects of LCA, DfE and SCM

5.5 Conclusion

LCA, SCM and DfE each have their own strengths and limitations. LCA considers environmental impacts over the life cycle of a product or a service. An LCA requires comprehensive inventory data where information should be collected throughout the value chain of the product. The popularity of outsourcing means that parts of the actual products for which the LCA is undertaken, can be produced in different locations world-wide and make it difficult to gather specific data. Some of the suppliers of such parts might be direct suppliers or sub-suppliers for the company producing the product for which the LCA is performed. Serious impacts can appear much further away in the supply chain. SCM therefore requires a significant level of stakeholder involvement when increasing an organization's awareness around sustainability. The interorganizational dimension of SCM results in both coordination and monitoring challenges. The combination of LCA and SCM is an appropriate approach to reduce environmental impacts and costs via different mechanisms to drive the production of products and services towards sustainability. Similarly, LCA is an important and helpful tool for gathering information feeding into the DfE-process. DfE and SCM both address environmental issues through design and innovation to influence companies' strategic decisions. They thus contribute to the further development of principles for integrated models for the achievement of sustainable design as a sustainable solution: either as a product, or, as a service. This has become a growing field of research across different disciplines, and a rich field for interdisciplinary collaboration.

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Chapter 6
Communicating Product Life Cycle Performance through Labels and Declarations

Christofer Skaar

Abstract This chapter gives an overview of the development of different eco-labelling schemes over a timeline of about 50 years. The main focus is, however, the standards for product declarations developed under the ISO 14000-family. Hereunder standards for product categories rules (PCRs), environmental product declarations (EPDs) as well as standards for different eco-footprints as, for example, carbon footprints of products (CFP) and water footprints of products (WFPs). The chapter also gives a brief description on how to develop and implement product labels for various purposes.

6.1 Introduction

Companies are increasingly held accountable for their performance on sustainability. This is an established trend that also extends to the products and services that companies provide. Expectations to report on environmental performance come from many stakeholders, such as professional buyers, individual consumers, consumer advocacy groups, environmental organisations, and the government. Companies can try to meet these expectations through product level reporting, where product level refers to both products and services. This is especially relevant when communicating on issues that are not possible to discern from the product itself. One cannot see the carbon footprint of a product and one cannot tell if the wood in a product is sourced from sustainably harvested wood or not.

Using labels and declarations to communicate product environmental performance has a long history, as shown in Fig. 6.1. Two early examples are the Demeter label and the Blue Angel, both from Germany. The Demeter label was founded in 1928, allowing customer to choose products from biodynamic agriculture (Demeter 2022). The Blue Angel label was founded in 1978 and is considered as the first

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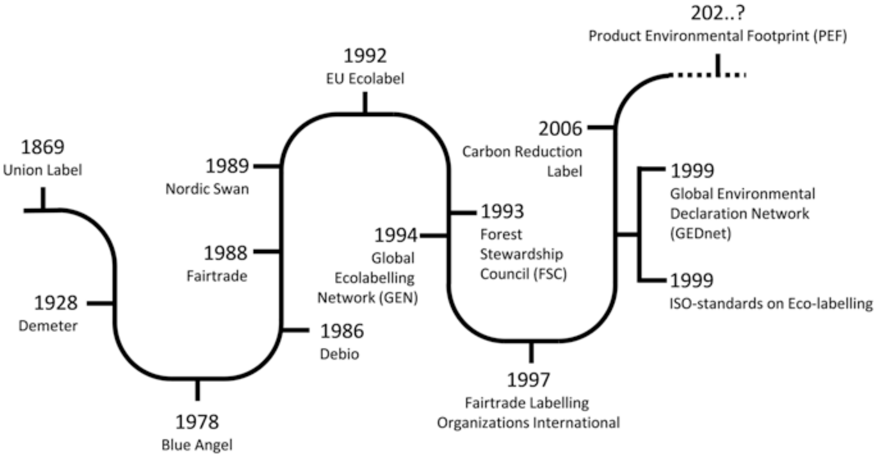

Fig. 6.1 Timeline of environmental communication for products

proper ecolabel (UNOPS 2009), with multiple criteria and a life cycle perspective. In the decades after the introduction of the Blue Angel, there was global growth in environmental labels and declarations. The EU has worked on developing and testing a methodology called Product Environmental Footprint (PEF) since 2011. As of 2022, in its transition phase, it is expected to have significant impact if and when it is introduced into EU law (EC 2022).

With the increase in labels and declarations, there was a need for more cooperation between the organisations. There was also a need for stakeholders to be able to understand the quality of different programmes – which labels and declarations can be trusted? In short, there was a need for standardisation. Through the International Organisation for Standardisation (ISO), the development of a series of ISO standards was started in the late 90s. These are known as the ISO 14020 series of standards and they provide principles for communicating environmental performance through labels and declarations (ISO 14020: 2000, 14025: 2006, 14021: 2016, 14024: 2018a).

6.2 Environmental Labels and Declarations

The ISO 10420 series of standards provides three different approaches for communicating on the environmental performance of products and services (ISO 2000, 2006, 2016, 2018a). Each approach has its own standard, and they are labelled type I, II and III by ISO. They must all follow the nine general principles outlined in ISO 14020, where the key message is that environmental claims must be based on science, be verifiable, be accurate and relevant, and not be misleading. Note that it is not uncommon for an organisation to use more than one of these approaches at the same time, for example to meet requirements in different markets or by different stakeholder groups. The three approaches (label type and ISO standard) are:

- Self-declaration (type II, ISO 14021)
- Verifying content (type III, ISO 14025)
- Certifying performance (type I, ISO 14024)

Table 6.1 provides an overview of key differences between the three approaches. *Main audience* indicates if the primary audience is professional or consumers, termed business-to-business (B2B) versus business-to-consumer (B2C). Public procurement will usually be considered B2B, but smaller procurements may also be considered as B2C. *Programme* indicates if there is a requirement for an organisation (programme operator) responsible for running the ecolabel system.

The ISO standards provide three archetypes for ecolabels: Type I, Type II, Type III. The archetypes provide a framework for understanding product level communication. However, we often find labels and declarations that are a mix of these archetypes. These are referred to as hybrid labels. One hybrid label has become so common that it has its own ISO standard, this is ISO 14067 for reporting on the

Table 6.1 The ISO 14020 family and beyond: environmental claims for products and services

				Hybrid approaches		
	Type I	Type II	Type III	Footprint labels (ISO 14026)	Carbon footprint (ISO 14067)	Other hybrid approaches[1]
Standard	ISO 14024	ISO 14021	ISO 14025	ISO 14026	ISO 14067	*Check*
Main audience	B2B and B2C	Depends on claim	Mainly B2B, B2C possible	B2B and B2C	For communication, ISO 14026 applies	*Check*
Programme operator	Yes	No	Yes	(Yes)[2]		*Check*
Life cycle perspective	Yes	(Yes)[3]	Yes, LCA	Yes		*Check*
Environmental performance criteria	Multiple criteria	Self-imposed criteria, often single issue	No performance criteria	No (but rating scales may be used)[4]		*Check*
Verification type	Yes, 3rd party	No, based on disclosure	Independent verification. 3rd party for B2C, programme decides for B2B	Independent verification. Programme decides for B2B and B2C		*Check*

[1] This column provides a checklist for evaluating environmental labels and declarations – if you encounter an unfamiliar label, you can use this as a guide to evaluate it
[2] There is a requirement for programme operator, but a company can be its own programme operator
[3] A life cycle perspective is encouraged, but not required
[4] In general, no performance criteria are used. However, it is possible to use rated scales (e.g. A–E, 1–6, etc.) based on defined performance levels

carbon footprint of products (CFP) (ISO 2018b). The growth of demand for single issue declarations, such as carbon through CFP and for water through water footprint of products (WFP) has led to the development of ISO 14026 for communication of environmental footprints.

6.2.1 Type I: Environmental Labels

Environmental labels of type I are probably the labels that are best known by people in general, as they can be found on products such as groceries, clothing, and furniture. Two examples of such labels are the Blue Angel from Germany and the Nordic Swan, founded in the 70s and 80s. Historically, the main audience of environmental labels were in the business to consumer market. However, over the last few decades they have been commonly used for all types of procurement (B2C, B2C, public procurement).

The purpose of these labels is to certify the environmental performance of the product against a set of defined criteria. These criteria are developed from a life cycle perspective and often also include quality requirements. The intention of labelling is then to make it easier to identify good quality products with a low environmental impact.

The basic principles for a type I label are to provide information that is accurate and verifiable. Furthermore, it must focus on relevant environmental aspects and not be misleading. The criteria are developed through stakeholder consultation and based on scientific methodology. There is also a requirement that the label must be administered by an independent organisation (programme operator): the procedure, methods and criteria must be transparent.

6.2.2 Type II: Environmental Claims by Manufacturers

Environmental claims of type II are self-declared, for example, made by manufacturers and retailers, and can be found, for example, in advertisements, on products, in technical brochures and on websites. The ISO 14021 standard was developed due to a growth of claims related to environmental performance and a need to ensure the reliability of these. These are often used for claims related to one or a few environmental aspects, such as recycled content, recyclability, biodegradability, energy consumption, and so forth.

For self-declarations, transparency is a key element. The company may evaluate the environmental performance of a product and communicate this, but they must also provide information to anyone that wishes to verify the claim. For verified content, there are no environmental performance criteria that the product must fulfil, and the customers must themselves evaluate and compare between products.

6.2.3 *Type III: Environmental Declarations*

Environmental Product Declarations (EPD) of type III quantify the environmental performance per functional unit for a product system. The *functional unit* is a key concept and is a quantification of the performance of the product system. For example, a chair's function is to *provide seating*. This may be quantified with a functional unit as *to provide seating for 15 years*. The EPD is based on a life cycle assessment (LCA), which shall follow requirements specified in Product Category Rules (PCR). These requirements are based on the LCA methodology and are developed through stakeholder consultations. There is also a requirement that the EPD system shall be administered by an independent organisation (programme operator) and that the procedures, methods and requirements are transparent.

The purpose of an EPD is to provide verified information but note that there are no environmental performance requirements for the product itself – this must be evaluated by the user. EPDs are typically used in business-to-business (B2B) communication and public procurement, as the volume of information make them less suited for business-to-consumer (B2C) communication. Evaluation and comparison based on EPDs should be based on the functional unit in a life cycle perspective.

6.3 Future Trends: Carbon Footprint of Products (CFP) and Other Hybrid Labels

This is a continually developing field and not all labels and declarations fit neatly into type I, II and III categories from ISO standards. Instead, a label may have elements from more than one type, and we can call these hybrid labels. The carbon footprint is perhaps the best known of these hybrid labels. It has elements of all three types: it is a label on the product, may have performance requirements, it is for a single issue, and it provides quantified information. The EU's work on developing the Product Environmental Footprint (PEF) may result in a hybrid approach – potentially combining a quantified declaration with performance-based labelling (EC 2022).

A common trait for all labels is that they are developed to meet a perceived market need. Some may have a life cycle perspective and cover all relevant environmental aspects, but often they are for single environmental issues. For these it should be noted that there is a danger of problem shifting, reducing the environmental impact in one area at the expense of increased impact elsewhere.

6.4 Application

The large volume of labels and declarations in use makes it difficult for companies to choose a label/declaration that best serves their needs and requirements. Finding the right approach is a balancing act where stakeholder requirements, company strategy, and resources must be considered. A key challenge is that there is no single approach that will satisfy all stakeholders. Demands may vary across markets, industries, and customer types, and continue to develop over time. The choice of approach should be developed based on the organisation's environmental strategy and environmental ambition level.

6.4.1 Choosing an Approach

Organisations have a range of strategic options from which to choose. Roome (1992) defines a range of *ambition levels*, from leading edge to non-compliance. This range can also be linked to environmental ambitions for the product system (Level 2 in the CapSEM Model):

- Leading edge: the performance of the products is among the best and the organisation contributes to advancing the industry.
- Commercial/ environmental excellence: the performance is among the best; the environment is used to gain competitive advantage.
- Compliance plus: performance is above minimum requirements but not good enough to obtain a type I ecolabel.
- Compliance: performance meets minimum legal requirements, but there are no defined targets to improve beyond this.
- Non-compliance: the organisation knowingly breaks laws and regulations to gain competitive advantage, e.g. through greenwashing.

Ecolabels of type I can be used in the two highest *ambition levels* to help ensure that the product is among the best. Products with these labels are usually among the top 10–20% in the product category (Minkov et al. 2020). A challenge here is that outperforming the criteria does not give immediate advantage. Declarations of type III can be used to ensure that legal requirements are be met. This can be used in all but the non-compliance ambition level. It can be used as documentation of compliance and as documentation of being on the leading edge. It is also possible to use a combined approach, for example using type I labelling to show general excellence on a range of products, with additional type III declarations to show outstanding performance on a selected issue (e.g., carbon footprint) or selected products (e.g., a line of outstanding products). It is also possible to combine environmental and social aspects when reporting, broadening the scope of the declaration (Skaar and Fet 2012).

For the highest ambition levels, we need to determine what good environmental performance constitutes. Type I ecolabels and type III environmental declarations can provide insight into which environmental aspects are relevant from a life cycle perspective: labels add performance levels for specific aspects.

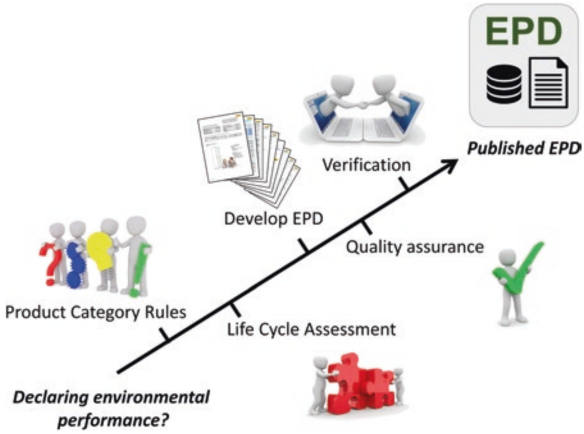

Fig. 6.2 Steps: from deciding to use EPDs to a published declaration

6.5 Creating an EPD

Figure 6.2 provides an overview of the key steps required to develop and publish an EPD for a product or a service. The first step is to decide that the EPD is the preferred type of environmental label or declaration, as discussed in the previous chapter. The next step is to either identify or develop a set of Product Category Rules (PCR) for this type of product. The PCR is typically developed by EPD programme operators and detail the rules and requirements for the Life Cycle Assessment supporting the EPD. The purpose of the PCR is to ensure that EPDs are harmonised and comparable. The next step is performing the LCA. A company can choose to either use in-house expertise or engage a consultant. When the EPD has been developed and gone through an internal quality assurance check, it is ready for independent verification. Verification must be carried out by a verifier approved by the EPD programme; it is also often a requirement to have third party verification. Having gone through the verification, the EPD is ready for publication. It is the EPD programme operator who publishes EPDs, and these are typically published as a document or a dataset, or both. For companies with a large product portfolio, it is becoming increasingly common to streamline this process through EPD tools, which reduce the workload per EPD published (Fet et al. 2009).

6.6 Conclusion

This chapter has provided an overview of environmental labels and declarations. The main Level in the CapSEM Model for labels and declarations is Level 2, the product system. However, communicating product performance is not enough on its own to contribute to sustainable development. The labels and declarations are end results. To improve the environmental performance of products and services it must be integrated into a system of continual improvement at multiple levels:

- Level 1. Processes: Labels and declarations can contribute to identifying the most significant processes in an environmental perspective, both within the organisation and in the value chain.
- Level 2. Product system: Labels and declarations can contribute to product design and supply chain management.
- Level 3. Organisation: Labels and declarations can contribute to obtaining and maintaining a license to operate, and to gain competitive advantage
- Level 4. Larger systems, such as the society: Labels and declarations can contribute to changes in consumers' behaviour by informing selections on climate footprint of their consumptions.

Elements that may contribute to competitive advantage may be direct (e.g., customers' willingness to pay a premium, gaining market access, winning tenders) or indirect (e.g., positive effect on reputation, increased capacity and knowledge base, better stakeholder communication). However, there are also risks associated with environmental labels and declarations, for example, that costs are higher than gains, the chosen label lacks customer trust, or the risk of focusing on the wrong environmental aspects.

Environmental labels and declarations are an effective tool for communicating environmental performance for products and services, but their potential goes beyond this, such as a mechanism for communicating corporate responsibility regarding products (Skaar and Fet 2012). Integrating the use of labels or declarations in an organisation's environmental management system can ensure continual environmental improvement, contribute to reduce risks, and help to identify win-win opportunities.

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Chapter 7
Environmental Management Systems

Annik Magerholm Fet and Ottar Michelsen

Abstract This chapter gives an overview of the history of the development of environmental management systems (EMS) and the purpose of an EMS. It expands on the description of the different steps of an EMS under the model Plan-Do-Check-Act and clarifies the use of concepts within EMS. Companies are motivated by external pressure from stakeholders, national and international authorities, customers demanding greener products etc., as well as the ability to attract new employees and avoid negative publicity. Standards belonging to the ISO 14000-family for environmental management include both product-related standards and audit and evaluation standards.

7.1 Introduction

An environmental management system (EMS) supports organizations in implementing their environmental policy. There are multiple reasons for an organization to recognize the need for an EMS. External pressure from stakeholders, national and international authorities, customers demanding greener products etc. motivate some companies, as well as the ability to attract new employees and avoid negative publicity (Sharma 2000; Epstein and Roy 2001; Mosgard et al. 2022). The implementation can also be the outcome of using methodologies presented in Chaps. 4–6. Starting with an intention to improve the processes and the value chains of their products, these tools will contribute to a better understanding of the environmental aspects of the organization. Through the implementation of cleaner production (CP) and design for environment (DfE) principles, the general environmental perfor-

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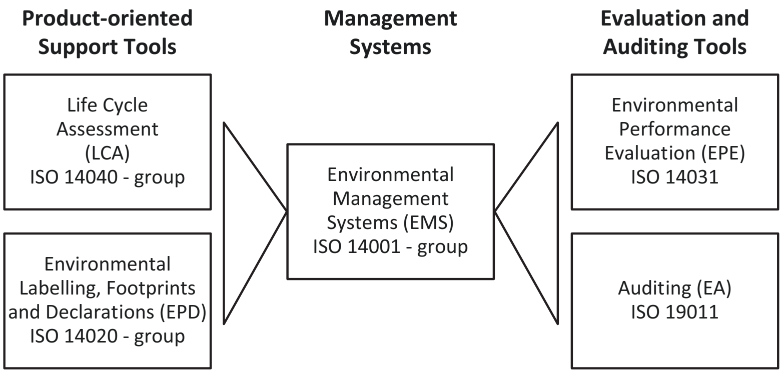

Fig. 7.1 Product-related standards and audit and evaluation standards underpinning environmental management. (Illustrated by examples from the ISO 14000-family)

mance is improved by reduced material throughputs and lowered energy use (Eagan and Pferdehirt 1998). This will most often lead to upgrading management procedures, which further leads to the improvement of environmental policies, routines and strategies in the company. This, in turn, will contribute to a more comprehensive understanding of the benefits of a systematic approach toward the environmental challenges encountered by most organizations today. This is illustrated in Fig. 7.1, which shows a sampling of standards belonging to the ISO 14000-family for environmental management. Note that these include both product-related, and audit and evaluation, standards. A better insight into the performance of the processes often also results in improved business performance (Darnall et al. 2008; Mosgard et al. 2022).

7.2 Environmental Management Systems Background

The world's first standard for environmental management was launched in 1992, namely the British Standard BS 7750, which was quickly followed by the European Eco Management and Audit Scheme (EMAS) in 1993, and later the International Organization of Standardization, the ISO 14001, standard on environmental management in 1996 (Delmas 2002). The British Standard BS 7750 has been withdrawn, but the others have been revised and the present version of ISO 14001 is from 2015 (ISO, 2015). EMAS has been updated with indicators set for different sectors and recommends ISO 14001. Even though there are differences, an EMS should include procedures for understanding the environmental aspects, setting objectives and targets, establishing programmes to achieve those objectives and targets, and reviewing performance against those objectives and targets.

An EMS is based on the environmental policy of the organization, with the EMS being the tool to bring this to life (Fet 2006; Fet and Knudson 2017; Johnstone 2020). An environmental policy is a written statement defining the company's aims

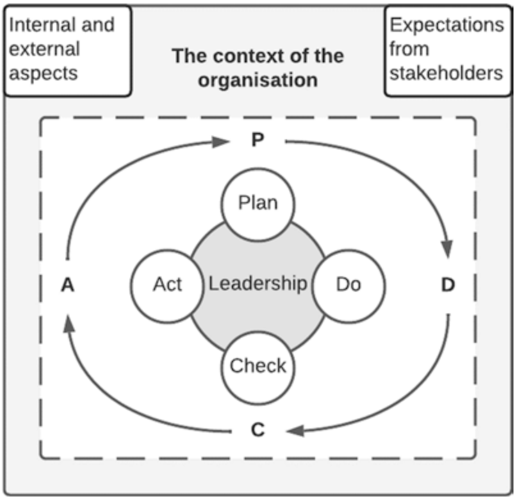

Fig. 7.2 Methodology for Implementation of Environmental Management Systems with Leadership at the centre

and principles on managing the environmental effects and related aspects of the company. The policy should comply with national and international regulations and other obligations signed by the company as well as fulfill the ambitions of the company. A company should decide if they just want to use an EMS to ensure it avoids breaking any legal constraints, or if the ambition is to demonstrate its control of the environmental performance as a competitive advantage (Michelsen and Skaar 2021). In the latter case, an environmental policy should set the rules and guidelines for how a company should operate and shape its organization.

To be effective, an EMS should be integrated with the overall management system which includes the organizational structure, responsibilities, practice, procedures, processes and resources for determining and implementing the environmental policy. When an environmental policy is adopted, the programme should follow the plan-do-check-act-review cycle through continuous improvements as illustrated in Fig. 7.2. The context of the organization must be understood, the needs and expectations of those involved in the organization, including shareholders and the surrounding society as well as obligations in relation to compliance. Figure 7.2 makes the importance of leadership explicit and outlines the roles and responsibilities required for the management of a strong EMS.

7.2.1 The PLAN Stage in an EMS

The PLAN stage in an EMS is rooted in a description of the activities and processes of an organisation. It describes how its environmental policy is operationalized. An important part of this initial planning is to identify stakeholders and their requirements, to consider both environmental aspects and associated environmental impacts, and to understand the laws, regulations and standards with which the organization must comply. An understanding of the context in which the organisation operates is also of great importance in addressing management challenges.

7.2.1.1 Stakeholders

Stakeholders are individuals or groups who may gain or experience losses or harm as a result of company operations. Stakeholders can be employees, customers, suppliers, local communities, governments, nongovernmental organizations, or shareholders. Stakeholders can be engaged in a variety of ways, such as:

- focus groups meetings
- online discussions
- meetings in local communities (“Townhall” meetings)
- engaging a stakeholder panel, expert panel or external review panel
- involvement in partnerships

It is important to involve stakeholders who are directly affected by the environmental aspects of the company, both its activities and possible aspects of its products and services, with the possibilities of minimizing any negative impacts. A similar approach should be used for the social aspects (Edinger-Schons et al. 2020).

7.2.1.2 Environmental Aspects

Environmental aspects are defined as activities, products or services that might impact the environment (ISO 2015). When planning the implementation of an EMS, an overview of any potential environmental aspects that may occur as a consequence of the company’s activities and products should be created. By drawing maps and flow diagrams of all relevant activities and material flows, potential environmental aspects can be identified and listed. Documentation should include descriptions and flowcharts of existing processes, production data (e.g., raw materials consumption, production volume, emissions to air, water and soil, energy consumption, secondary products and waste, noise and vibration), transport, potentially also transport of employees, and storage of raw materials, products and waste. This should result in all environmental aspects being fully documented, and, as far as possible, an estimation of the amounts of resource usage, water consumption, and emissions and waste generated by the various processes involved. Initial surveys of environmental aspects are often qualitative and provide an opportunity for prioritizing areas needing attention. Material flow schemes and process flow diagrams, (see Chap. 4) can are useful for rendering a more quantitative overview. An important decision at this point is in designating appropriate limits for the EMS and identifying environmental aspects. Is the focus on internal processes only, or should aspects within the value chain which are upstream and downstream also be included? The answer to this depends on the type of company involved and the context of its operations, together with its environmental policy.

7.2.1.3 Environmental Impacts

Based on the list of environmental aspects drawn up, the next step is to understand their severity by analyzing any potential impact on the environment. Impact on the environment can be local, regional and/or global. In order to understand the consequences, one must know the cause – effect response of the different emissions and their impact on the environment and eventually on human health. Figure 7.3 illustrates the pathway for determining environmental impacts caused by an aspect which is, *the use of fossil fuel in transportation*. The burning of fossil fuel causes a number of emissions into the air, e.g., NO_x, SO_x, particulate matters (PAM), CO_2, VOC and others. Each of these has a distinct impact on the environment. If we look closer at the CO_2 and VOC, they are categorized as greenhouse gases with an impact on global warming followed by a potential impact on climate change. The impact that NOx and Sox have on acidification could be illustrated in a similar manner and analyses could be completed for each identified aspect.

There are no standardized methods for assessing environmental impacts, so organizations are encouraged to establish procedures for determining which aspects have the most significant impact on the environment. It is important to have in mind that environmental impacts are not limited only to emissions. Impacts caused by land use, land transformation and resource extraction and potentially depletion should also be included. Normally, data achieved from input-output (I/O) analyses, material flow analyses (MFA) and life cycle assessment (LCA) information form the basis of the registration of environmental aspects and related impacts caused by the company's activities, products and services.

For smaller firms with limited resources for a full assessment, a simplified impact assessment can be conducted where the company identifies a priority list of what is regarded the most important aspects. For the example of emissions above (Fig. 7.3), CO_2-emissions will have global impact through global warming, while SO_x may

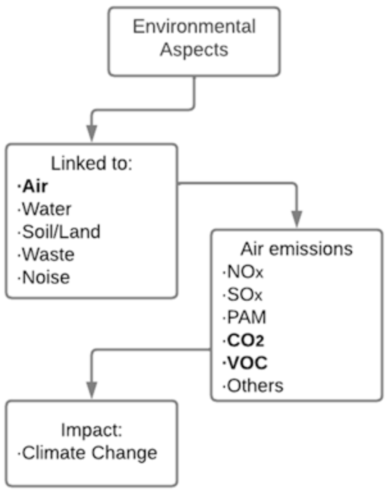

Fig. 7.3 Illustration of pathway from aspects to impacts: emissions from *the use of fossil fuel in transportation* to the impact on climate change caused by CO_2 and VOC-emissions. (Modified from Winther and Fet 2016)

cause acidification with a regional impact. Similarly, particulate matters may cause bad air quality, and thereby have local impact. As for other activities land use and potential impacts on biodiversity could be the most relevant aspect. As part of the management system, the company should implement procedures for how to evaluate and take action for the most significant aspects for their company. Chapters 8 and 9 on indicators and reporting practices provide a more in-depth analysis of environmental impact assessments (EIA).

7.2.1.4 Environmental Improvement Programmes

The planning stage should also include consideration of environmental improvement objectives, and furthermore, how to achieve them. This should include objectives related to activities, processes and products, which in the next turn involve operations as well as value chain control, emergency preparedness, monitoring and measurements. Proposals for environmental improvements may refer to:

- Product and process changes
- Changes in raw materials and auxiliaries
- Changes in technology and practices
- Alternative measures for waste reduction
- Reuse or recycling
- Energy conservation
- Land restoration and/or biodiversity precautionary actions
- The possibilities for environmental improvements can be considered in different ways. Based upon the list of identified environmental aspects, a priority-list for improvements should be made. The next step should then be to select the measures for improvements. The action plan should specify:
- the schedule for implementation of measures
- assignment of responsibility
- training plan for employees, introduction of new equipment, new operating instructions, etc.
- documentation of the effectiveness of the chosen measures.

A set of environmental goals and agreed-upon programmes ready for implementation, signify the shift from the PLAN to the DO-stage.

7.2.2 The DO Stage: Implementation

This part of the management system focuses on implementation of measures for improving environmental performance. Procedures for implementation, monitoring, control and documentation of the progress should be established. In case of emergency situations, the organization must plan and implement a process to determine preventive actions to minimize the risk for accidents that can result in negative impacts on the environment.

The DO stage further requires that the organization shall determine and provide the resources and competence needed for the implementation of programmes and procedures, ensuring continual improvement of the environmental performance. Environmental statements form the basis for determining new objectives and related action plans or environmental programmes. The organization shall further plan how to respond to external interested parties as required by its compliance obligations.

7.2.3 The CHECK Stage: Monitoring, Verification and Auditing

The objective of the CHECK stage is to ensure the project sits within rules and regulations and company policies, and that the plans are appropriate to meet the environmental objectives set.

The *monitoring* activity should concentrate on following up on the environmental improvement objectives and programmes, thereby *verifying* whether the environmental performance is improved according to the plan.

The purpose of an *audit* is to uncover weaknesses or discrepancies and to examine whether the systems and procedures are adopted and work as intended. This is done by obtaining audit evidence and judging it objectively to determine the extent to which the audit criteria are fulfilled. The audit is completed when all activities set out in the audit plan have been completed. Follow-up measures should be listed in the audit report. ISO 19011 (ISO 2018) provides guidance on how to carry out audits, and the audit programme shall include procedures for the audit and the follow-up of the audit, and reporting to management.

Another purpose of an audit is to begin a dialogue in relation to any potential challenges the company might encounter due to an increasing focus on sustainability relating to activities, products, and services. Checklists for future scenarios could therefore support companies wishing to be at the forefront of developments, and thereby turn such challenges into opportunities.

A final part of the CHECK stage is the management review. The organization must evaluate environmental performance and provide input to management for review of the effectiveness of the EMS. The audit report is one of the underlying documents for the management review.

7.2.4 The ACT Stage: Action for Improvement

The last stage in the PDCA-circle is ACT. This means that the organization should react to any non-conformity and take action to eliminate the causes of these and implement corrective actions. An important part of this is also an evaluation of the company's environmental policy to determine if it should be revised. This is a task for top management.

7.3 Conclusion

According to the principles presented in this chapter, an EMS is the tool for bringing the environmental policy of the organization to life. EMS is also a tool that helps organizations reach and document their compliance regarding laws, regulations and own targets and ambitions. The target for the EMS is therefore to establish procedures and good practice to achieve the objectives given in the policy. EMS should support strategic business management: strengthening the relationship between environmental management and the core business of organizations.

According to the ISO 14001 standard (ISO 2015), an organization must accept responsibility for the impact caused by its activities, products and services. Due to the increased sustainability challenges the world is facing, the attention given to an organization's performance is also increasing. The discussion is how far reaching such responsibility should be. As a result of the UN Sustainability Development Goals (SDG) (United Nations 2015), especially SDG 12 on responsible consumption and production, the responsibility should address the entire value chain of a product, that involves sustainability aspects both upstream and downstream in the chain (Michelsen and Skaar 2021). Aspects related to end-of-life treatment of the products should be included and possibilities to circulate materials into new products, should be identified. This requires that the EMS has procedures for analyzing the impact outside the factory gate, which means an increased focus on life cycle thinking (Mosgaard et al. 2022). This should be visible in the environmental policy as well as in the procedures to be used for the understanding of the most significant environmental aspects and impacts.

An EMS is designed to mainly address environmental aspects. It can be extended to a management system to also include social and economic aspects. The structure could be the same, but the written material should then include procedures for identifying these aspects, and also criteria for carrying out an audit connected to economic and social performance. With an increased focus on holistic and life cycle thinking, new standards for sustainability management systems are expected to appear in the future (Nawaz and Koç 2018).

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Chapter 8
Analytical Frameworks, Impact Categories, Indicators and Performance Evaluation

Annik Magerholm Fet

Abstract This chapter introduces the background for indicators to be used to monitor and communicate the environmental performance of different systems and activities. They are anchored in the DPSIR-analytical framework which stands for driving force, pressure, state, impact, and response. This framework is fundamental to our understanding the background for many of the tools and standards for analyzing, measuring, communicating, and reporting on environmental performance. DPSIR has been developed as a global model for understanding and analyzing the status of the Earth due to changes in environmental conditions and how to respond to these changes. The model can also be adapted for smaller systems, for example, for city or regional systems (Level 4 in the CapSEM Model), for organizations (Level 3), for products systems (Level 2) and for productions processes (Level 1).

8.1 Sustainability Indicators

At the United Nations conference on Environment and Development in Rio de Janeiro in 1992, the society decided to debate the topic 'Indicators of Sustainable Development' as stated in Agenda 21 (UNCED 1992), which was later signed by most nations. This was further described in the action programme for activities into the twenty-first century addressing the combined issues of environmental protection and equitable development for all and laid the foundation for current UN Sustainable Development Goals (Bell and Morse 2018).

The term *indicator* comes from the Latin verb *indicare*, meaning to *disclose or point out, to announce or make publicly known, to estimate or put a price on.* Indicators are normally used to communicate information and to draw attention to the performance of current policies. Indicators provide information in more quantitative form than words or pictures alone, and they also provide information in a simpler form than complex statistics or other kinds of social, economic, or scientific

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data. In the OECD-definition from 1993, two major purposes are described (Hammond et al. 1995):

- they reduce the number of measurements and parameters that otherwise would have given an exact presentation of a situation, but are difficult to obtain, by providing approximately aggregated measurements
- they simplify the communication process in which measurement results are provided to the user

Indicators therefore tend to be a *proxy* for the best accumulated knowledge available.

An indicator should reflect changes over a period keyed to a problem, be reliable and reproducible, and be calibrated in the same terms as the policy goals or targets to which they are linked. Indicators must be understandable. They must reflect the goals one seeks to achieve and give information that is meaningful for interested parties. Indicators are not an end in themselves, but tools to build support for needed change and guide the actions of management. Indicators communicate information about progress toward stated goals.

The United Nations' Commission for Sustainable Development (UNCSD) encouraged the development of a core set of Sustainability Indicators, mainly on economic and social issues (UNCSD 1995). However, there was a lack of established comparable international indicators to help decision makers to evaluate environmental trends (Hammond et al. 1995; Moldan and Dahl 2007). Environmental indicators (EI) should be subject to frequent reconsideration as conditions of the environmental change. The plan was that indicators should facilitate international compilation. They should guide data collection, even though each nation would have its own priorities for data collection and analysis, reflecting local needs for resource management and environmental regulation. However, if each country is using different indicators or different methodologies, international agencies cannot work effectively, and opportunity for countries to cooperate to solve global or continent-wide environmental issues could be lost.

By using sustainability indicators industry and other organizations have been guided in how to approach their sustainability performance improvements since the 1990s. There is still a need for placing environmental performance in context so that firms can understand how to contribute to sustainable development in the long-term with a reasonable chance for economic benefits, as well as in the short-term.

8.2 Selecting Indicators: Approaches

Indicators can be selected by employing a bottom-up or a top-down approach. The top-down approach typically starts from international or national rules and regulations, while bottom-up indicators are most commonly based on available data. Primary data can be processed, summarized and expressed by indicators. The information expressed through indicators can be further weighted and aggregated into an index. Weighting and aggregation should be done with care to ensure verifiability,

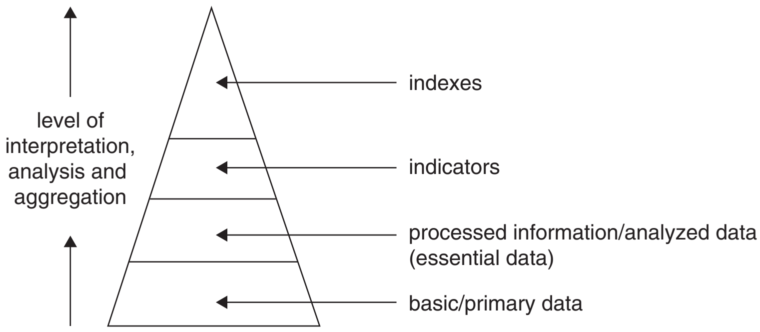

Fig. 8.1 An indicator information pyramid

consistency and comparability. Indicators may have many components based upon measured parameters, but the number of final indexes should be as few as possible. Hammond et al. (1995) produced an *Indicator Information Pyramid* interpreted in Fig. 8.1.

8.2.1 Top-Down Approach

A top-down approach starts with indicators at national and international levels. National indicators can show citizens and decision makers which trends are on course and whether current policies work. They can also provide a framework for collecting and reporting information within nations and for reporting national data to international bodies. Indicators are used to build support for much needed change and guide governments, international organizations, the private sector, and other major groups to act more sustainably. In order to structure *sustainability information* and to make it more accessible to decision makers and the public, various conceptual frameworks have been proposed. A widely used framework for environmental indicators is based on the following simple questions:

- What is happening to the state of the environment or natural resources?
- Why is it happening?
- How can we improve it?

This approach is often called the *Pressure-State-Response* (PSR) approach, see Fig. 8.2. Indicators are used to communicate the interactions between man-made and natural systems (the environment). The pressure corresponds to the extraction of resources *from* the environment or emissions *into* the environment. Pressure indicators are direct measures of policy effectiveness e.g., related to increase of emissions and waste, and support the decision-making process. The state indicators correspond to the condition of the environment. Response indicators express the societal response, which often leads new regulations being developed. For example, for climate change, pressure indicators express emissions of climate gasses, such as

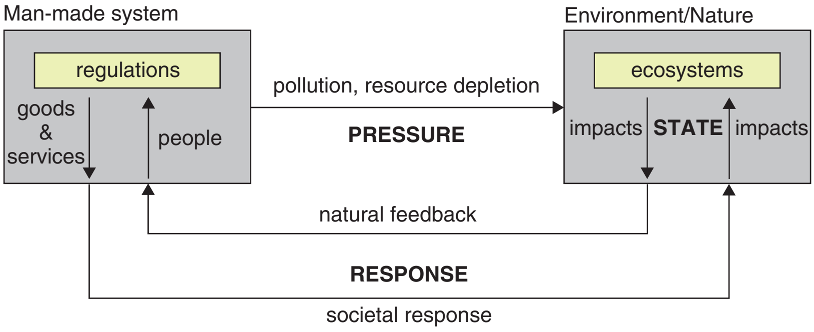

Fig. 8.2 Pressure-state-response (PSR) framework for indicators

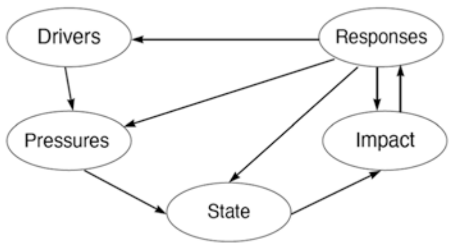

Fig. 8.3 Framework for Reporting on Environmental Issues. (Modified from EEA 1999)

CO_2, the state indicators express atmospheric concentration of greenhouse gases and the global mean temperature and response indicator may be expressed by requirements for increased energy intensity or the reduced use of fossil fuels. For toxic contamination, the generation of hazardous wastes is expressed by pressure indicators. The state indicators express the impact and the response indicators are expressed through new regulations.

The PSR-framework was further developed into a framework which distinguished driving forces, pressure, states, impact and responses. This became known as the Driver-Pressure-State-Impact-Response (DPSIR) framework which has been widely used by international policymakers. DPSIR gives a structure within which to present the indicators needed to enable feedback to policy makers on environmental quality and the resulting impact of the political choices made, or to be made in the future (Kristensen 2003; Reid and Rout 2020; Carr et al. 2007). For each of the DPSIR-stages, information can be expressed and communicated by indicators (see Fig. 8.3).

Driving Force Indicators

A ‘driving force’ is a need, and for an industrial sector a driving force could be the need to be profitable and to produce at low costs, while for a nation a driving force could be the need to keep unemployment levels low. Other forces could be the need for specific materials or energy, or the need for land areas to build a facility. A driving force indicator should be designed appropriately to match the need.

Pressure Indicators

As early as 1994, OECD classified human interactions with the environment in four broad categories: 1. Use of natural resources, 2. Flows of pollutants and emissions, 3. Impact on the ecosystem and reshape of the environment and 4. Effect on human welfare caused by environmental conditions.

1. *Resource index and source indicators.*

Indicators in this area directly measure the sustainability of natural resource use, so they signal the effectiveness of natural resource policies. Roughly, the index indicates the degree of departure from sustainable resource use, assuming that the depletion of natural resources is sustainable if their use leads to the creation of other assets of equal value.

2. *Pollution/emission index and sink indicators.*

The pollution index is described by six impact categories (OECD 1994): climate change, depletion of the ozone layer, acidification of soils and lakes, eutrophication of water bodies, toxification of soils, water bodies and ecosystems, and accumulation of solid waste. For each of these there are supporting indicators. Each impact category can be weighted based on the gap between the current value of the indicator and the long-term policy perspective of sustainability, the greater the gap, the larger the weighting factor.

3. *Biodiversity index, ecosystem risk and life support indicators.*

Biodiversity can in some sense be measured on a species level by counting species or listing endangered species. A biodiversity indicator consists, for example, of a summary of national statistics.

4. *Human impact index and exposure indicators.*

This concerns human welfare, the environmental conditions that undermine it, and the social equity. The indicators compare how environmental conditions influence a nation's human welfare. This index could provide important environmental information; it could be combined with other health information to create an overall health index to be used as an indicator of sustainable development.

State Indicators

As a result of pressures, the state of the environment is affected. State indicators should be designed to reflect the quality of air, water, soil and ecosystems, tracking the state of the environment over time. Both physical, chemical, and biological conditions should be measured by state indicators.

Impact Indicators

The changes in the physical, chemical, or biological state of the environment determine the quality of ecosystems and the welfare of human beings. In other words, changes in the state may have environmental or economic impacts on the

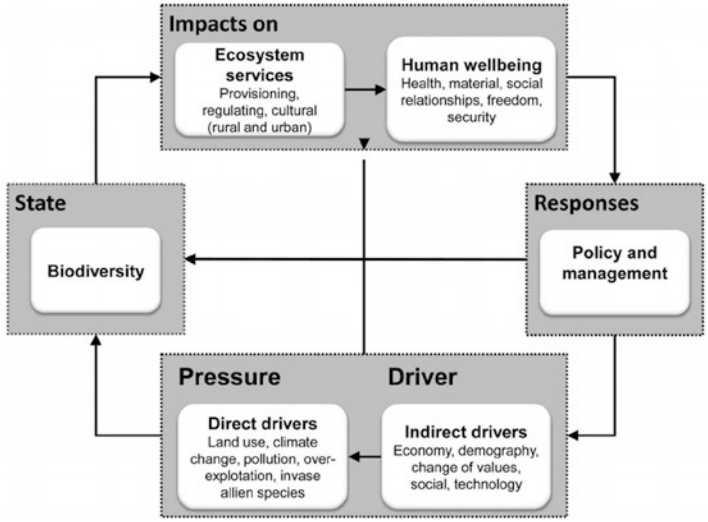

Fig. 8.4 Example of DPSIR with reference to impact on ecosystem services. (Santos-Martín et al. 2013)

functioning of ecosystems, their life-supporting abilities, and ultimately on human health and on the economic and social performance of society (EEA 2003). Impact indicators should be designed to reflect and monitor changes over time.

Response Indicators

A response by society or policy makers is the result of an undesired impact and can affect any part of the chain between driving forces and impacts as indicated by the arrows in Fig. 8.3. An example of a response to driving forces might be new legislation in transportation systems. A response to pressure could be adjusted to permit a change in the content of nitrogen in wastewater discharges to lakes.

Figure 8.4 gives an example of how the DPSIR framework can be used for a study on drivers that put pressure on biodiversity with an impact on ecosystem services and resulting consequences to human wellbeing. The responses are, in this example, new policies and regulations to avoid damage to ecosystem services.

8.2.2 Bottom-Up Approach and Environmental Performance Indicators

Whereas a top-down approach works best for issues impacting the global environment, a bottom-up approach is more commonly adopted for issues with local environmental impacts. The four pressure indicators presented in the previous section could also be a reference for approaches on a company level. At a macro-level, the national governmental institutions like statistical offices, normally gather and aggregate company based environmental data from the micro level. Environmental information and statistical data are normally supplied to national and international institutions by companies. Therefore, it is important, practical, time and cost- effective to structure company based environmental information systems in such a way that they are compatible with, and useable for, the macro level. Although this was addressed in the early 1990s, the need for harmonization remains an issue. According to ISO 14031 (ISO 2021), environmental performance (EP) is defined as the result of an organization's management of its environmental aspects. According to ISO 14001 (ISO 2015), environmental aspects are defined as activities, products or services that can make an impact on the environment. The pathway from aspects to impacts is described in Chap. 7 (Fig. 7.3).

8.3 Environmental Performance Indicators and Evaluation

An environmental performance indicator (EPI) is defined as a specific expression that provides information about an organization's environmental performance (ISO 2021). Firms should select EPIs for the purpose of measuring, evaluating, and communicating their performance. Measuring one single firm's contribution to the degradation of global environmental issues is impossible. Likewise, it is challenging for a company to predict how their reduction of, for example, CO_2-emissions contributes to reduced global warming. From a bottom-up-approach, the corporate's EPIs should reflect the most important environmental aspects resulting from internal processes connected to the activities, products, and services of the company. A sample approach to identify appropriate EPIs might be as follows:

1. Identify environmental aspects connected to activities, products and services (e.g., use of fossil fuels) and then the impacts this may cause (e.g., emissions of CO_2 which may cause global warming, or particles that may cause smog).
2. Analyze the organization's existing data on material and energy inputs, discharges, wastes, emissions, and other outputs. Assess these data in terms of quantity and hazards, often termed as the environmental account for the company.
3. Identify the views of stakeholders and other interested parties and use this information to help design the EPIs.

An organization that is committed to improving its environmental performance, should be able to measure its performance level. According to ISO 14031 (ISO 2021), EPIs will help them determine whether they are moving forward with the intention to improve. Environmental Performance Evaluation (EPE) is the process that organizations can use to measure, analyze, and assess their environmental performance against a set of criteria. From the perspective of the CapSEM Model, this takes place within the organization at Level 3 but uses I/O and LCA from Level 1 and 2. EPE helps the organization to understand its significant environmental aspects and form a baseline from which objectives and targets for improvements can be derived. Therefore, EPE is central for monitoring environmental performance improvements over time, and to compare the performance against another similar organization for benchmarking.

EPE can be developed for a relatively small application, even in a large organization. The process should include (1) establishing measurable goals and targets, (2) setting time schedules for the improvement tasks, (3) implementing action plans to achieve the goals, and (4) communicating the environmental performance to interested parties. As the environmental performance improvements spread within an organization, the EPE process can expand. Since environmental performance improvement should apply to all life cycle phases of a product or a service, data collection should also address relevant information outside the manufacturing site and based upon data from, for example, a life cycle assessment (LCA) of a product (ISO 2012).

The areas for EPE can be split into operational performance measured by OPIs and management performance measured by MPI. The operational area includes physical facilities and equipment, design and operation, and the material and energy flows required to generate and provide the products and services. Most EPIs are related to the operational area; they could also be expressed as operational performance indicators (OPI). According to ISO 14031 (ISO 2021), OPIs should provide information about the impacts resulting from an organization's operations. Similarly, a management performance indicator (MPI) is defined as an indicator that provides information about management (ISO 2021). The management area of an organization includes the policies, practices, people and procedures at all levels, and their decisions and activities, which in turn result in impacts on the environment. Environmentally related inputs to management include legal requirements, views of interested parties, information from the operational system, and information about the condition of the environment.

Examples of OPIs and MPIs are presented in Table 8.1. These can be used as inspiration for companies for internal performance improvements programmes, and EPE can then be carried out in relation to the goals set for each indicator for external reporting. OPIs and MPIs are mainly designed for evaluation internal practices. Another evaluation criterion is the evaluation of the state of the nature in the surrounding area. This can be carried out using Environmental Condition Indicator. The condition of the environment covers air, water, soil, flora, and fauna. Environmental condition indicators (ECI) should be selected regarding these categories. Evaluating the state of the environment caused by one single organization's activities is complex. In most cases, evaluation of the state of the environment will be undertaken by regional authorities or by help from consultants or scientific organizations. Good insight into the condition of environmental surroundings can assist an organization in planning the EPE process and selecting relevant EPIs.

Table 8.1 Examples of EPIs expressed by OPIs and MPIs

Example of operation performance indicators (OPI).	**Example of management performance indicators (MPI).**
Category – materials	**Conformance – degree of compliance with regulations**
Quantity of materials used per unit of product	Costs (operational and capital) that are associated with a product's or process' environmental aspects
Quantity of processed, recycled or reused materials used	Return on investment for environmental improvement projects
Category – energy	**Category - financial performance**
Quantity of energy used per year or per unit of product	Costs (operational and capital) that are associated with a product's or process' environmental aspects
Quantity of energy used per service or customer	Return on investment for environmental improvement projects
Category – emissions	**Category - implementation of policies and programmes**
Quantity of specific emissions per year	Number of achieved objectives and targets
Quantity of specific emissions per unit of product	Number of organizational units achieving environmental objectives and targets
Category – wastes	**Category - community relations**
Quantity of waste per year or per unit of product	Number of inquiries or comments about environmentally related matters
Quantity of hazardous, recyclable or reusable waste produced per year	Number of press reports on the organization's environmental performance

8.4 Other Frameworks for Evaluating Sustainability Performance

There are many frameworks, guidelines, and standards available for supporting business and other organizations in their efforts to use indicators in the process of evaluating their sustainability performance. At the same time, it is important to remember that indicators are designed to encapsulate complexity into condensed information, and it has long been known that sustainability indicators can be selectively used to support polarized sides of a given debate (Bell and Morse 2018). Chapter 9 gives an overview of the most recent and most used framework for driving performance improvements and for reporting and communicating business performance.

8.5 Conclusion

This chapter has presented various frameworks for choosing indicators that can be used for communicating sustainability performance on different systems levels. At the macro level, the DPSIR-model is a systematic approach for embracing the complexity involved when dealing with sustainability in a global society. On the micro level, the framework for EPE-evaluation is mainly designed for corporate levels and their activities, products, and services. DPSIR models use indicators for communicating aspects connected to the operational and management areas in a company. Even though none of the existing models provide a perfect link between the indicators selected from a top-down view with those from a bottom-up view, the DPSIR- and EPE-models offers guidance for companies and other organizations when selecting an indicator for communication purposes. The use of indicators and reporting practices is further described in Chap. 9.

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Chapter 9
Reporting Schemes

Annik Magerholm Fet and Magnus Sparrevik

Abstract This chapter gives an overview of different reporting schemes which can be used by companies to communicate their environmental, as well as their sustainability, performance. Connections between different reporting schemes, underlying data and the CapSEM Model are explained. The most common sustainability reporting schemes are described within the context of their intended use by the reporting organization. The chapter also addresses the content for writing a sustainability report together with the use of tools and performance indicators to present quantitative information.

9.1 Introduction

The term *sustainability reporting* is often used synonymously with *corporate sustainability reporting*, *triple bottom line reporting,* and *non-financial rep*orting, and refers to the reporting of non-financial aspects alongside existing financial reporting (Paun 2018). These reports may include information about the company's use of natural resources and their impact on the environment, relevant social aspects, or corporate governance. Sustainability reporting should therefore:

- Enable any type of organization to measure, manage and communicate its performance
- Communicate information that is of interest to stakeholders about a company's activities
- Contribute to building trust and manage reputational risk

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- Work as a benchmarking tool, where performance comparisons can be conducted internally, externally and over time.

Integrated reporting, defined as "a single document that presents and explains a company's financial and nonfinancial—environmental, social, and governance (ESG)—performance," is increasingly adopted by companies (Eccles and Saltzman 2011). This is due to increasing requirements for ESG disclosure from governments and market regulators and the growing recognition of the connection between risk and ESG factors and a resulting appreciation for sustainability reporting from investors and stakeholders (Eccles and Saltzman 2011).

Over time, sustainability reporting has gradually evolved. In the beginning, reporting was confined to non-financial aspects promoting environmental work as a part of building positive reputation. The reports were often more informative than accurate and varied significantly between the different actors (Paun 2018; Stacchezzini et al. 2016). The need for standardisation became evident during this time and the Global Reporting Initiative (GRI) standard was established in 1997 to improve the quality of reporting (GRI 2022). Parallel with this voluntary development, regulatory requirements to describe the work on the environment, anti-corruption, work environment and human rights emerged in national and eventually supra-national regulations. Even though sustainability reporting became compulsory, the impact of sustainability information remained marginal compared to the financial content. This picture has changed. The need for accurate information about sustainability performance is growing and is actively used by investors, banks, and insurance companies to evaluate risks and potential development. In fact, a good ESG record is becoming a prerequisite for financial investments, as well as regulatory requirements and therefore actively governs the future of individual companies (Fatemi et al. 2018).

9.2 Approaches to Reporting

Sustainable development reporting does not work as a *one-size-fits-all* approach. Each company should determine their own situation and needs. This is an evolving field, and in an effort to provide *standardized* information on sustainable development performance, appropriate frameworks for sustainable development reports continue to be developed (Sardianou et al. 2021; Lyytimäki and Rosenström 2008). A framework should help to harmonize reporting practices, and should ideally address these four elements (Fet et al. 2009):

- Firstly, the underlying concept of sustainable development and its application in an organizational context. Sustainable development often means different things to different people (Redclift 2006).
- Secondly, the objective of sustainable development reports. Sustainable development reports may be described as showing a balanced and reasonable presentation of an organization's economic, environmental and social performance.

- Thirdly, the characteristics that determine the usefulness of the information in reports, especially relevance and reliability.
- Fourthly, a framework should define the basic information incorporated in sustainable development reports.

A company's sustainable development report should allow users to compare its sustainable development performance and position over time to identify trends. Likewise, these reports should allow users to benchmark different companies to evaluate their relative performance and position, both regionally and within the same business segment. The framework elements should measure and report on the impacts of similar activities and processes in a consistent manner over time, which presents another dilemma, i.e., a need to trade-off between flexibility and comparability. When a company starts to practice sustainability reporting, they should have the flexibility to identify those indicators most relevant to their own specific circumstances and operations. Reporting guidelines should strive not only to increase the volume and complexity of the information requested, but favour reliability and relevance. Only a limited number of indicators should be required, allowing users to compare corporate practice on a general level.

Reporting principles must support transparency, credibility and accountability as well as ensure that the information and data is relevant, reliabile and clear. External reporting gives management an additional opportunity for improvement based on feedback through readers' reactions, criticisms, and suggestions. Considering stakeholder views also helps to shape strategy, goals and objectives. The reporting process should be an integral part of internal management procedures and a number of sources are available to assist in this process (Sahin and Çankaya 2020; Gbangbola and Lawler 2017; Searcy and Buslovich 2014).

As part of an overall management system, reporting should lead to an improved performance throughout the organization. In the CapSEM Model, reporting is placed at Level 3. However, reporting involves communicating the company's performance at all levels. At Level 1, this includes information about the quantities of materials and energy in and out of each production process, emissions, and wastes, summarized into an environmental account for the production site, and often communicated by means of operational performance indicators (OPIs). At Level 2, the commentary should address material flows along the entire value chain of the product (or service the company provides), most often calculated using life cycle assessment (LCA) and summarized in an environmental product declaration (EPDs), or other forms of product information, e.g., carbon footprint, (CFP) and water footprint (WFP), of products. Reporting management activity at Level 3 should encompass information from Levels 1 and 2 in addition to information about management and strategic matters (see Chap. 8 for management performance indicators (MPIs)). A company would also usually include information about its role and involvement on a societal Level: in the CapSEM Model this is represented by Level 4. For large corporates with production sites in different regions, for organization and communities, reporting should always include information about the impacts of related systems. The communication of performance on all levels should be carried out using

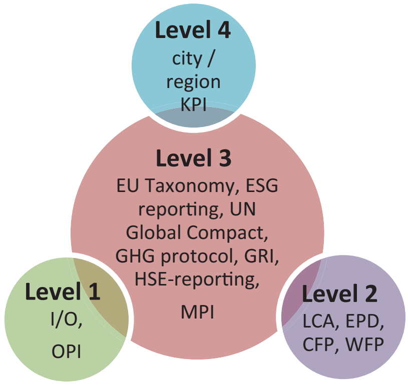

Fig. 9.1 Contributors to reporting content and practice (Level 3): relevant examples of tools and indicators. Levels 1, 2 & 4. (CapSEM Model)

performance indicators. Monitoring systems also need to be put into place. These can either be physical systems or procedures for tracking performance at each level. The objective of reporting schemes is to assist companies and organisations in their reporting. Figure 9.1 illustrates some of the reporting schemes most frequently used by an organisation.

A sustainability report can be compiled in various manners, based on a range of recommendations for what might be included (Gbangbola and Lawler 2017). The information to be presented in a report should be collected by using relevant tools, such as input-output (I/O) analyses on production processes, and value chain analyses tools for products. The information can be further communicated by means of operational performance indicators (OPIs), or by means of LCA-results summarised in product declarations and other label systems. The EU Taxonomy suggests a classification system aimed at establishing a list of environmentally sustainable economic activities at company level, but which can be seen as systemic, also connecting city regional key performance indicators (KPIs).

9.3 Sustainability Reporting Schemes

9.3.1 Environmental Reporting

Content for a sustainability report may overlap with other reporting obligations within a company. Thousands of companies worldwide hold a certificate on environmental management according to ISO 14001 or the European Environmental management and Audit scheme (EMAS). For ISO 14001-certified companies, drafting an environmental report is voluntary. However, EMAS-registered companies already have audited environmental statements as part of their verification in accordance with EMAS-regulation. The environmental aspects of a sustainability report should reflect the company's overall, real, conditions. This may involve information about environmental aspects in the form of:

- resource consumption: raw materials, materials and packaging, energy, water, land areas
- emissions: pollutants to water, air and soil, noise, dust/smoke, smell
- products: content of toxic substances, proportion of recycled materials, recoverable share
- waste: hazardous waste, for landfills, for recycling and for incineration

With regard to environmental aspects, the report should include quantified information, preferably in the form of performance indicators (Machado et al. 2021). Any numerical information should show the development over time, with graphic representations. Significant changes since the previous environmental report should be highlighted. If the company has had environmental accidents or unplanned discharges during the period covered by the report, this should be stated. Special emission permits that apply to the business, as well as any orders received from supervisory authorities during the reporting period, should be highlighted. If possible, the company should include information about any environmental impacts caused by significant environmental aspects together with any acute discharges caused. Environmental impacts can be grouped according to whether they are local, regional or global.

Results from environmental audits and environmental reviews, which have been carried out on the company's own initiative during the reporting period, should be described. Progress and results regarding measures from the company's environmental programme, environmental audits and environmental reviews as described in previous environmental reports, should also be reported. If the company has been subject to supervision by government agencies, the results of these inspections and audits should also appear in the report.

As an environmental management system should consider processes, products and services, the report should also include information about environmental aspects of products seen from a life cycle perspective. More specifically, this means incorporating information about the impacts of the use phase, maintenance and end-of life phase. The information can be achieved from LCA, from EPDs or other documentation simulating the life cycle of the product.

Finally, the company should report on its environmental management programme for improving health, safety and environment (HSE) whilst both quantifiying, and providing deadlines, for each individual environmental objective. The description of these environmental goals should include planned investments in connection with the measures to be implemented to achieve the goals. Expected cost savings and earnings opportunities should be reported as a result of reduced raw material consumption, new processes, increased market access, gains by avoiding regulations, reduced absence costs, etc.. If any of the conditions are significant environmental aspects, and are not included in the environmental programme, the rationale for excluding them, and ideally when the company will include them, should be explained in its plans for environmental improvement.

Information about the work environment should include human resources, work environment factors (ergonomics, indoor climate, psychosocial conditions, etc.), absence, stress disorders, other health damage (solvent damage, etc.). Safety aspects should include significant risk factors, risk prevention measures, emergency measures, damage to people, property and the environment.

9.3.2 Measuring Environmental, Social and Governance (ESG) Factors

Environmental, social and governance (ESG) factors can be used as a framework for reporting on a firm's sustainability performance. Environmental criteria consider how a company performs as a steward of nature. Social criteria examine how it manages relationships with employees, suppliers, customers, and the communities where it operates. Governance ensures that the company uses accounting methods with transparency and accuracy, pursues a leadership with integrity and diversity, and is accountable to shareholders.

ESG reporting can help a company communicate its contribution to sustainability through key performance indicators (KPIs) to reach environmental, social and governance objectives within the firm. KIPs can be structured according to the ESG-criteria by means of environmental performance indicators (EPIs), operational performance indicators (OPIs), management performance indicators (MPIs) as described in Chap. 8. Reporting on ESG factors is also important for external communication to customers and investors. Reporting on ESG factors is also important for external communication to customers and investors. Many investment banks have set their own ESG guidelines to mandate the compliance and screen their investments, and to distinguish those with the best sustainability performance. Performing well in terms of ESG principles, can therefore attract or maintain outside investment. Many financial actors now offer products that employ ESG criteria in the analysis and presentation of the financial instruments (Escrig-Olmedo et al. 2019).

9.3.3 Corporate Annual Reporting

There are different national rules for mandatory reporting for business. In their annual reports, businesses should report on their activities, and especially on their financial performance. The need for transparency has become stronger, and the Transparency Act of 2021 (Gullhagen-Revling et al. 2021) aims to provide a common standard and further tighten the legal obligations for companies to comply with both the UN Guiding Principles on Business and Human Rights and the OECD's Guidelines for Multinational Enterprises as well as the UN's sustainable development goals (SDGs). The Transparency Act is a part of a development in which obligations related to what has historically been considered *soft law* or obligations that *should* be fulfilled, are now legal obligations for companies. In this context, it is also interesting to note that the European Commission is steadily working on directives on sustainable corporate governance, with respect to enhancing the liability of board members. Assessments must be carried out regularly and be in proportion to the size of the company, the nature of the company, the context in which the company takes place and the severity of and the probability of negative consequences for basic human rights and decent working conditions.

9.3.4 Reporting for Cities

Sustainability reporting can also be adapted to cities. Cities are growing, and it is estimated that by 2050, cities will contain 70% of the world's population (Steinert et al. 2011). Challenges connected to use of resources, food supply, energy supply, wastes and emissions must be addressed beyond the individual corporate boundaries. While cities plan ways to meet sustainability challenges, indicators to measure the progress over time are developed accordingly alongside mechanisms to measure and track the indicators relying on digital (ICT)-solutions and artificial intelligence (AI-techniques).

As part of the 'United for Smart Sustainable Cities' (U4SSC) programme (Estevez et al. 2021; Sang and Li 2019), a set of 97 key performance indicators (KPIs) were developed. In addition, cross-country initiatives were put in place to benchmark cities against these KPIs. Similar KPIs exist for regions with the intention to measure progress both by municipalities and by businesses operating in the municipality. The same methodologies presented at each Level of the CapSEM Model can be used to aggregate quantitative information at the city level, which is represented by Level 4 in the CapSEM Model. Reporting on city levels is an ongoing process: it is expected this will grow in the future.

9.3.5 Examples of Reporting on Sustainability

A variety of reporting options for sustainability are available, each with a specific focus on different aspects of sustainable development. These include GRI reporting, reporting on greenhouse gas (GHG) emissions, the UN Global Compact, and the EU taxonomy.

9.3.5.1 GRI Reporting

GRI is the first global framework for comprehensive sustainability reporting, encompassing the *triple bottom line* of economic, environmental, and social issues. It has become the generally accepted, broadly adopted framework for preparing, communicating, and requesting information about corporate performance. Furthermore, it provides guidance to reporters on selecting generally applicable and organisation specific indicators, as well as integrated sustainability indicators (Dissanayake 2021; Machado et al. 2021; Roca & Searcy 2012). It also includes forward-looking indicators and targets for future years (Halkos & Nomikos 2021; Szennay et al. 2019).

9.3.5.2 GHG Protocol

The GHG protocol (WRI/WBCSD 2011) has established the most widely used standard for reporting on emissions of greenhouse gas emissions related to productivity. The standard divides emissions into three distinct classes depending on the source of the emissions. The GHG Protocol scopes emission across the value chain. Scope 1 emissions are direct emissions from owned or controlled sources emitting GHG. Scope 2 emissions are indirect emissions from the generation of purchased energy. Scope 3 emissions are all indirect emissions (not included in scope 2) that occur in the value chain of the reporting company, including both upstream and downstream emissions. Reporting on scope 1 and 2 are compulsory when using the protocol whereas scope 3 is voluntary.

All reporting is based on information aggregated at a product level (CapSEM Level 2) including all supply of services and products necessary for the company activities, the emissions for internal production process and the impacts foreseen for the downstream activities of the products or services produced. This life cycle perspective may be important for subsequent reporting by the company and for use in environmental management systems to mitigate impacts correctly in the value chain. Production companies with large emissions occurring from their own production may primarily address actions mitigating their own emissions and energy consumption based on assessment using the protocol. Consumers or service producers may, on the other hand, direct more effort towards green procurement to reduce the emissions on all products and services purchased (Fig. 9.2).

9.3.5.3 UN Global Compact

The United Nations Global Compact (UN 2021) is a strategic initiative that supports companies that want to demonstrate their compliance regarding awareness about sustainability. This is the most globally recognized framework for organizations. The initiative promotes activities that contribute to sustainable development goals and to align their strategies and operations with ten universal principles related to human rights, labour, environment, and anti-corruption, presented in Table 9.1. Companies that have signed the GC are obliged to submit annual reports. All such reports can be accessed through the UN GC website.

By incorporating the ten principles of the UN Global Compact into strategies, policies and procedures, and establishing a culture of integrity, companies are not

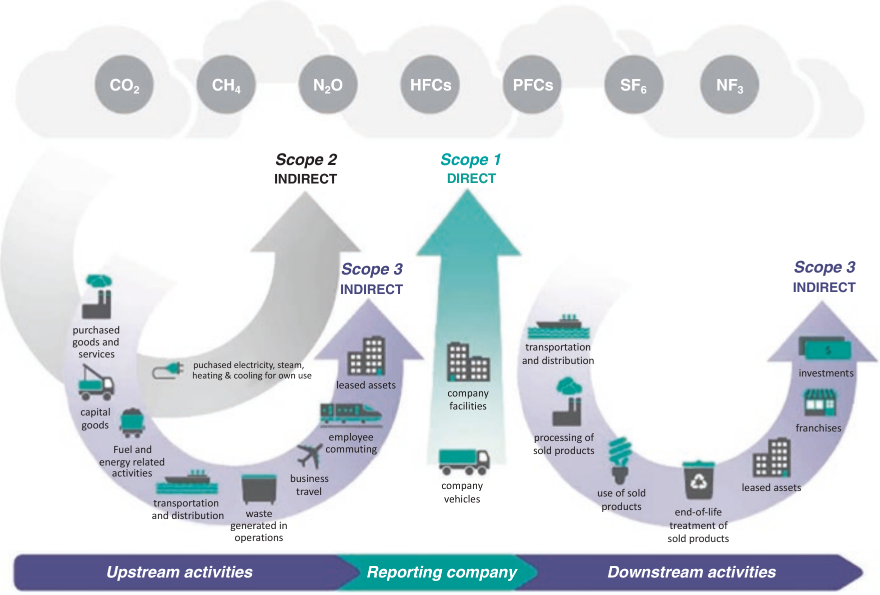

Fig. 9.2 Model of reporting according to GHG protocol. (WRI/WBCSD 2011)

Table 9.1 UN Global Compact ten principles (2021)

Human rights 1. Businesses should support and respect the protection of internationally proclaimed human rights; and 2. Make sure that they are not complicit in human rights abuses.
Labour 3. Businesses should uphold the freedom of association and the effective recognition of the right to collective bargaining; 4. The elimination of all forms of forced and compulsory labour; 5. The effective abolition of child labour; and 6. The elimination of discrimination in respect of employment and occupation.
Environment 7. Businesses should support a precautionary approach to environmental challenges; 8. Undertake initiatives to promote greater environmental responsibility; and 9. Encourage the development and diffusion of environmentally friendly technologies.
Anti-corruption 10. Businesses should work against corruption in all its forms, including extortion and bribery.

only upholding their basic responsibilities to people and planet, but also setting the stage for long-term success. There is no simple reporting template that covers all 10 principles of the Global Compact, however an annual Communication on Progress (CoP) report should be executed including the following minimum requirements:

- A statement by the Chief Executive expressing continued support for the UN Global Compact and renewing the participant's ongoing commitment to the initiative

- A description of practical actions the company has taken or plans to take to implement the Ten Principles in each of the four areas (human rights, labour, environment, anti-corruption)
- A measurement of outcomes

9.3.5.4 EU Taxonomy

On 18 June 2020, the EU Parliament and the Council adopted the EU Regulation 2020/852 on the establishment of a framework to facilitate sustainable investment. The EU Taxonomy emerged from the EU Green Deal initiative and is the first standardised and comprehensive classification system for sustainable economic activities that are responsible for up to 80 percent of EU greenhouse gas emissions. The intention is to help investors to make informed decisions by channelling investments into low-carbon technologies (Dusík & Bond 2022; Schütze & Stede 2020).

The regulation on the establishment of a framework to facilitate sustainable investment identifies six environmental objectives for the purposes of the taxonomy: Climate change mitigation; climate change adaptation; sustainable use and protection of water and marine resources; transition to a circular economy, waste prevention and recycling; pollution prevention and control; and protection of healthy ecosystems (Alessi et al. 2019). It also sets out four conditions that an economic activity must meet to be recognised as aligned with the taxonomy (Alessi et al. 2019: 4), which are:

- making a substantial contribution to one environmental objective (minimum)
- doing no significant harm to any other environmental objective
- complying with minimum social safeguards
- complying with the technical screening criteria

These are further cascaded into technical screening criteria and described in technical guidelines for each activity sector and objective (Canfora et al. 2021). The screening criteria set detailed threshold values at process, product, and company level for the environmental performance in the definition of 'substantial contribution to the objective' and 'in doing no significant harm' respectively.

9.4 Conclusion

Sustainable development reporting is not a one-size-fits-all activity. Each company should determine their own situation and needs to communicate their corporate situation. Some reporting is mandated, others, voluntary. Some reporting targets the global community, others are aimed at selected audiences. Regardless of the situation, there is a cornucopia of reporting schemes and associated guidelines to support most needs. Firms must choose carefully to reveal the appropriate information at the appropriate time. Moreover, transparency in reporting as defined in transparency regulations (Transparency Act, 2022) will be important regardless of the reporting scheme selected, to ensure the general public have access to sustainability performance and for the avoidance of any potential adverse impacts of the organisation's activity.

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Chapter 10
Business Models for Sustainability

Haley Knudson

Abstract The concept of *business models for sustainability* (BMfS) has attracted research attention in the fields of corporate sustainability, entrepreneurship and management. BMfS are a way of linking sustainable innovation to an organization's business model, and as a means for management to operationalize sustainable activities and strategies across an organization's value chain. This chapter provides the history and description of BMfS as both a tool and conceptual logic that divides activities into three components – value proposition, value creation and delivery, and value capture. Practitioner tools are introduced, along with a brief conceptual overview.

10.1 Background

Sustainability at a societal level is dependent on the sustainable development of organizations. Agenda 2030 and the UN Sustainable Development Goals (SDGs) have highlighted the importance of industry's involvement in the necessary shift in the current economic system (United Nations General Assembly 2015; Sachs et al. 2020; United Nations 2020). Traditional business models are unsuitable for meeting global sustainable development (SD) challenges (Wells 2013). *Business models for sustainability (BMfS)* are a concept that can help bridge the gap between the sustainable innovation necessary for SD and the strategies employed by organizations (Boons et al. 2013).

Research on BMfS has emerged to link sustainable innovation to the business model of an organization and its stakeholder network. It is a means for management to ideate and operationalize sustainable activities, mechanisms, and innovations from a system perspective. For this reason, BMfS are located on Level 3 of the CapSEM model, as they provide a structure and logic for the creation and capture of sustainable value. Methods and perspectives from Levels 1 and 2 for reducing

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negative and increasing positive sustainability impacts can be operationalized through the organization's business model as it links these operational activities to the wider value creating logic. Research on BMfS continues to expand and asserts the need for the incorporation of stakeholder interests and social and environmental values into an organization's strategy (Stubbs and Cocklin 2008; Boons and Lüdeke-Freund 2013; Bocken et al. 2014). Organizations can use business model thinking to reflect on their current operations and to find ways to redesign and innovate to meet sustainability needs and objectives across all Levels of the CapSEM Model.

10.2 BMfS Concepts

This section presents key concepts used in the study and implementation of BMfS, summarized in Table 10.1.

10.2.1 Business Models

A *business model* (BM) represents the way a company creates and captures value (Chesbrough 2010; Osterwalder and Pigneur 2010; Zott et al. 2011). Traditionally, this means the activities and resources that combine to allow the organization to

Table 10.1 Important concepts for understanding BMfS

Concept	Definition
Business model (BM)	"A business model describes the rationale of how an organization creates, delivers, and captures value" (Osterwalder and Pigneur 2010:14).
Business model for sustainability (BMfS)	"A business model for sustainability helps describing, analyzing, managing, and communicating (i) a company's sustainable value proposition to its customers, and all other stakeholders, (ii) how it creates and delivers this value, (iii) and how it captures economic value while maintaining or regenerating natural, social, and economic capital beyond its organizational boundaries" (Schaltegger et al. 2016: 6).
Business model innovation (BMI)	"The conceptualisation and implementation of new business models. This can comprise the development of entirely new business models, the diversification into additional business models, the acquisition of new business models, or the transformation from one business model to another. The transformation can affect the entire business model or individual or a combination of its value proposition, value creation and deliver, and value capture elements, the interrelations between the elements, and the value network" (Geissdoerfer et al. 2018: 405–406).
Business model innovation for sustainability (BMIfS)	"The conceptualisation and implementation of sustainable business models." (Geissdoerfer et al. 2018: 405–406). "Sustainable business innovation processes specifically aim at incorporating sustainable value and a pro-active management of a broad range of stakeholders into the business model" (Geissdoerfer et al. 2016: 1220).

meet its objective of delivering value to its customers, while also creating a profit. It is a reflection of a firm's strategy (Casadesus-Masanell and Ricart 2010; Seddon et al. 2004; Shafer et al. 2005; Richardson 2008) and, on an operational level, can provide the organizational and financial architecture of an organization including its understanding of its customers and their needs (Teece 2010). The BM and its activities can be structured around a common framework of three components – value proposition, value creation and delivery, and value capture (Richardson 2008; Chesbrough 2010; Osterwalder and Pigneur 2010). *Value proposition* refers to the organization's product or service offering, and the value embedded within it. The organization's activities and processes, including its resources, suppliers, partners, and distribution, represent *value creation and delivery*. *Value capture* is the organization's cost structure and revenue streams.

In practice, the BM can be a helpful tool for thinking about an organization's strategy. It can help outline or conceptualize an organization's value activities, and the way in which they interact, impact customers and stakeholders, and help meet corporate strategy and its goals. As responsibility in the value chain becomes a more pressing requirement from regulators, customers and stakeholders, organizations need to change the way in which they do business. They can use their current BMs as a starting point for brainstorming and thinking systemically about how they can shift to new or adapted business models that create and capture value across economic, environmental, and social dimensions.

10.2.2 Business Models for Sustainability

BMs for sustainability present an opportunity to affect larger societal and environmental change by transforming the value that guides organizations and the current market. They also provide a vehicle for organizations to increase their long-term value and competitive advantage (Porter and Kramer 2019). The BMfS definition presented in Table 10.1 extends the traditional BM components into the sustainability domain, as presented in Fig. 10.1. Distinguishing characteristics of a BMfS include the explicit and proactive consideration of stakeholders, of environmental,

Fig. 10.1 BMfS components

social, and economic capital, and that the organization looks beyond its own boundaries and over the long-term perspective (Schaltegger et al. 2016; Geissdoerfer et al. 2018). BMfS are placed on the organizational change level (Level 3) of the CapSEM Model because they provide a common framework within which the organization can discuss its current operations, partners, stakeholders, suppliers, and value flows. By viewing its BM as a system of activities, a company can work on identifying where and how changes can be made in the process (Zott and Amit 2010).The long-term outlook is an implicit requirement of SD, and it is important that organizations specifically integrate it into their strategies, performance measures and BMfS. Additionally, stakeholder needs over the long-term must be actively and intentionally integrated into BM processes and activities, so that the organization's activities reflect and meet them.

Embedding the three dimensions of sustainability, long-term thinking, and the engagement of all stakeholders into a BM requires an organization to understand how its activities, resources and relationships interact to create value. Conceptually, the *value proposition in a BMfS* extends beyond its goal of highest economic return and removes the purely economic value an organization associates with its product or service (Boons and Lüdeke-Freund 2013). It reflects the fact that the relationship between the organization and its customers and stakeholders is based on an exchange of value (wants and needs), rather than on the product or service itself (Bocken et al. 2014). If the customer wants to purchase a product with a lower environmental footprint, for example, they may be willing to pay more to have the same need met, or even sacrifice some functionality for social and environmental benefit.

Drawing attention to its position in a larger system, *value creation and delivery in a BMfS* is based on sustainable supply chain processes, such as the supply of resources, and production and transport activities, that reduce ecologic and social pressure. Impacts on stakeholders and environments across the life cycle and value chain must be considered (Boons and Lüdeke-Freund 2013). Improved processes may allow the seizing of new opportunities, revenue streams and markets, e.g., through recycling and closed-loop systems or creating new markets based in sustainable and efficient design or production (Bocken et al. 2014). Organizations can use the perspectives and tools from Levels 1 and 2 of the CapSEM Model to better orientate their production processes and value chain activities towards sustainability. Examples of innovation for sustainability in value creation and delivery could be new technology for improved resource efficiency in production, redesign of transport systems or improved labor conditions and worker's rights. These innovative activities also require the organization to look beyond its own boundaries and consider the needs of local communities and stakeholders. Such a perspective requires applying the thinking embedded in Level 4 (systems change) of the CapSEM Model.

Value capture in a BMfS recognizes the value awarded to the organization in performing in an environmentally and socially beneficial way that meets economic, environmental and social needs, and produces more than monetary profit (Boons and Lüdeke-Freund 2013; Bocken et al. 2014). It is structured in a way that helps to balance the value the organization associates with social, environmental, and economic costs and benefits. The value capture also "describes how part of the value generated for a stakeholder can be transformed into value useful for the company" (Geissdoerfer et al. 2018). Placing value on a reduction in resources or emissions, or on the benefit of creating community programmes, can then work its way into the organization's overall cost-benefit structure. More advanced value capture structures might incorporate leasing or sharing schemes that reduce traditional consumption patterns and collect payments per use or time-period rather than one-time purchases.

10.2.3 Business Model Innovation for Sustainability

The process of conceptualizing, adapting, or changing a BM to one that fosters sustainability is a development that requires a shift in the logic and system of interacting value components of the organization. This process can be referred to as *Business Model Innovation for Sustainability* (BMIfS). Conceptual clarity between the terms *business model* and *business model innovation* remains ill-defined (Foss and Saebi 2017; 2018; Geissdoerfer et al. 2018). However, one can generally distinguish between the BM as the system of interacting components, and BMI as "designed, novel, nontrivial changes to the key elements of a firm's business model and/or the architecture linking these elements" (Foss and Saebi 2017). For sustainability-based BMI, an organization must undertake more than single innovations that, for example, reduce the environmental impact of a single production process. Instead, it requires a broader and more complex understanding of innovations, and whether and how they transform and permeate through the business model, including the logic and processes that create, exchange and capture value for sustainability.

Another essential aspect of BMIfS is the holistic consideration of all components. BMfS components must be considered outside of their individual boxes since the activities within them are intertwined with activity processes within the others. Reflecting on these core aspects, the next section presents principles and tools for operationalizing BMfS and innovating a BM for sustainability.

10.3 Developing a Business Model for Sustainability

This section presents tools and guiding principles for innovating an organization's BM for sustainability. Based on their sustainability goals, an organization may choose to take a *defensive*, *accommodative* or *proactive* approach to innovating its BM (Schaltegger et al. 2016). These range, respectively, from making small incremental changes to mitigate risk and reduce cost, to improving internal processes that consider sustainability on some level, to the redesign of the core logic of the business for sustainable value (Schaltegger et al. 2016). To reach the more mature levels of BMIfS, important attributes that may help an organization in the process are (Stubbs and Cocklin 2008):

- Treating sustainability as a strategy in itself
- Using triple-bottom-line reporting for measuring and communicating progress e.g., SDG targets and indicators or the Global Reporting Initiative (GRI)
- Taking the stakeholder view of the organization
- Embedding sustainability into top management so it makes its way into organization processes and culture
- Recognizing nature and the environment as key stakeholders

Practitioner tools for BMI for sustainability ideation and development also come in different forms. Taking an *inside-out approach*, some tools begin with mapping an organization's current BM elements along sustainability dimensions to identify areas for reducing negative or increasing positive sustainability impact (Joyce and Paquin 2016). Other approaches take the *outside-in perspective* and look to types of BMIfS that have worked for other organizations and have been categorized into archetypes (Bocken et al. 2014; Joyce and Paquin 2016). The next sections briefly introduce two alternatives for organizations depending on whether they would like to start by first mapping their current BM, or by looking to successful sustainability or BM innovations of outside organizations. The approaches are not exclusive and should be combined for greater knowledge building, inspiration, and development.

10.3.1 Mapping a Business Model for Sustainability

Applying the BM concept from the operational level can be valuable as a mapping tool of component parts. Expanding the framework of three BM components, a business model canvas (BMC) takes an inside-out perspective to identify areas for innovation across nine "building-blocks" of the BM (Osterwalder and Pigneur 2010). In addition to the value proposition building block, value creation & delivery are divided into key partners, activities, and resources, and customer segments, customer relationships, and delivery channels. Value capture in a BMC is represented by segments of cost structure and revenue streams. *Business model canvases for sustainability* help organizations map their BM elements in a set architecture and in relation to their social and environmental performance objectives (Foxon et al. 2015; Upward and Jones 2016; Tiemann and Fichter 2016; Joyce and Paquin 2016). Explicitly viewing activities as components that interact as a system, helps to highlight their connections and the way each influences the others, potentially exposing areas for sustainable value creation.

In extending the original BMC for traditional BMs, numerous canvases have been developed to integrate sustainability dimensions, e.g., (Foxon et al. 2015; Upward and Jones 2016; Tiemann and Fichter 2016; Joyce and Paquin 2016).

Some studies have shown that mapping tools may have a limited effect on implementing designed innovation strategies (Morris et al. 2005; Demil and Lecocq 2010; Boons and Lüdeke-Freund 2013; Geissdoerfer et al. 2018). However, mapping different BM elements and functions across a generalizable framework can be a helpful starting point for visualization, ideation, and communication purposes within an organization.

The *triple layered business model canvas* (TLBMC) (Joyce and Paquin 2016), extends the original economic focused BMC to include additional layers for environmental and social value creation. The TLBMC should be performed in two steps – first as a baseline outlining the current BM and interactions, and then to identify areas for sustainable innovation opportunity.

The TLBMC has been selected for presentation in this chapter because the additional layers force an organization to specifically consider each of their BM components in relation to environmental and social aspects and impacts. Other BMCs for sustainability add important sustainability components, but not in the comprehensive way that the TLBMC embeds them The TLBMC mandates focus on interactions between the building-blocks on each layer (horizontal coherence), but also between and across the layers (vertical coherence) for systemic consideration of activities and stakeholders.

In addition to the economic layer, the environmental layer of the TLBMC requires an organization to take the life cycle perspective when identifying their environmental impacts. It specifically focuses on addressing the impacts of value creation & delivery activities such as material selection and supply, production processes, distribution, and impacts through use- and end-of-life phases. The environmental layer strongly encourages the use of quantitative indicators for measuring impact, and many of the Level 1 and 2 CapSEM model tools can therefore be applied. The social layer takes a stakeholder management approach to help the organization identify the impacts of relationships and interactions with its stakeholders including guidelines for local community engagement, organization governance, and management of employee, customer and societal culture. This helps the organization understand the flows of value within their value network, and to recognize opportunities for creating and capturing social value in their BMfS.

10.3.2 Business Model for Sustainability Archetypes

From an outside-in approach, BMfS have been classified into *archetypes*, or common models, based on the way(s) in which the models work to create and capture sustainable value (Bocken et al. 2014, 2016). The archetypes identified by Bocken and colleagues are categorized according to the type of mechanism or innovation that helps the organization deliver on sustainability – technical, social or organizational (Boons and Lüdeke-Freund 2013; Bocken et al. 2014).[1] While the categorization was performed to make sense of the growing literature in the field, the clear groupings and naming of archetypical models now provides both scholars and practitioners with common forms and patterns to discuss and reflect upon in the business model innovation process.

Technical archetypes are characterized by technical innovation in the business model through, for example, design or manufacturing processes that are more resource efficient and/or support the principles of the circular economy. *Social* grouped archetypes depend on social innovation to offer sustainable value, such as through a change in the functionality they offer the customer or a change in consumer behavior. *Organizational* grouped archetypes focus on restructuring the organization and its value creation, possibly as a reorganization of ownership, social or hybrid enterprises or base-of-the-pyramid business models that veer away from traditional company profit maximization structures (Bocken et al. 2014, 2016). Figure 10.2 presents the eight sustainable business model archetypes, and some examples, grouped by their innovation type (Bocken et al. 2014). Table 10.2 describes each of the archetypes across the BM elements of value proposition, value creation and delivery, and value capture (D'Amato et al. 2020).

Archetypes can also be grouped based on their foundational principles, e.g., the circular economy (Lacy et al. 2014; Lewandowski 2016; Lüdeke-Freund et al. 2019), or by their main value creation area – mainly economic, social-economic, social, mainly ecological or integrative (Lüdeke-Freund et al. 2018). The categorization of common patterns can provide inspiration to organizations working to improve the sustainability of their BM. Archetypes point out specific innovations that can transform the current BM or create an entirely new BM. They can be helpful in reconceptualizing current processes and identifying potential opportunities.

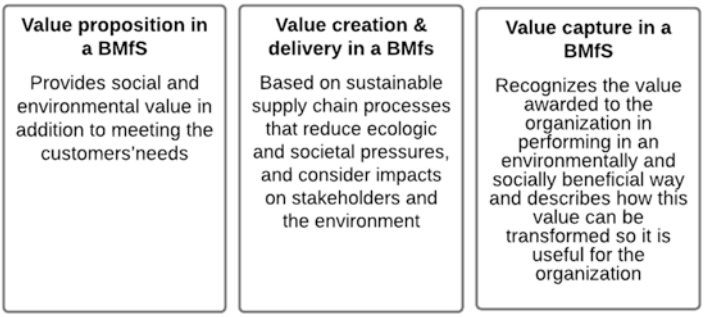

Fig. 10.2 Sustainable business model archetypes. (Bocken et al. 2014). doi: 10.1016/j.forpol.2018.12.004

[1] The technological, social, organization groupings were later updated to environmental, social and economic groupings (Bocken et al. 2016) paralleling triple bottom line dimensions, and a ninth archetype of 'inclusive value creation' added under the organizational/economical grouping. The original grouping is still most widely used, however, and therefore presented in the chapter.

Table 10.2 Sustainable business model archetypes along business model components

	Archetype	Value proposition	Value creation and delivery	Value capture
Technical	Maximize material and energy efficiency	Products/services using less resources, generating less waste and emissions	Adopting more efficient and safe production processes	Reducing costs, minimizing environmental impact
	Create value from waste	Turning waste into higher value products/services	Using recycled materials, ensuring recyclability of products/services	Reducing costs, as well as waste and virgin material use
	Substitute with renewables and natural processes	Products/services using bio-based renewable materials and energy	Adopting innovative production processes based on bio-based materials and energy	Commercializing new products/ services, reducing environmental impact
Social	Deliver functionality, rather than ownership	Shifting from a consumer to a user logic	Enabling product/ service reuse and reparation	Commercializing user-based solutions, reducing material use, enabling consumer access to expensive products/ services without owning
	Adopt a stewardship role	Providing access to more sustainable alternatives	Seeking resource co-management and transparency in supply chains	Securing a customer base by leveraging stewardship of social and ecological systems
	Encourage sufficiency	Products /services that reduce demand or consumption	Promoting responsible consumption and frugality (e.g., by ensuring product/ service longevity)	Encouraging premium pricing, customer loyalty, increased market share, reducing material use
Organizational	Repurpose the business for society/the environment	Prioritizing social and environmental benefits along with economic profit	Developing hybrid business, cooperatives	Establishing a new business while securing livelihoods and/or supporting natural systems
	Develop scale-up solutions	Expanding product/ service commercialization	Developing adequate infrastructure and partnering with additional operators	Sharing and promoting sustainability-oriented businesses, e.g., through licensing

Redrawn based on D'Amato et al. (2020). doi: 10.1016/j.forpol.2018.12.004

10.4 Conclusion

This chapter has provided an overview of the conceptual framing of BMfS, along with some of the practitioner tools that can be used by organizations to begin adapting, transforming, or creating new BMs that support sustainability objectives. BMfS are placed on the organizational level (Level 3) of the CapSEM Model because they can be used by management to visualize and understand the way the organization's activities combine and interact to create and capture value. To improve or better orientate their BM toward sustainability, BM activities must incorporate and combine environmental, social, and economic dimensions over a long-term perspective with the active consideration of stakeholders. Organizations should therefore apply and utilize the methods and tools associated with each of the Levels of the CapSEM Model to establish and measure the impacts of their activities within and beyond their business model. For example, Level 1 and 2 tools can be used to measure the material flows and life cycle impacts of production processes and value chains which can subsequently be incorporated into the value proposition and value creation and delivery elements of the business model. Changes in the material flows or resource use can then make their way into the value capture activities of the BM. Furthermore, management can apply other organizational level tools (Level 3) to manage, track, report and communicate their progress toward sustainability indicators, and identify areas where they are not meeting selected performance indicators. The organization must make strategic decisions to root sustainability in its organizational strategy so that sustainability objectives also drive the development and innovation of its BM. Corporate social responsibility (CSR) could be one such perspective for helping ground the BM in sustainable practices. Finally, to gain an overview of the network of actors and interdependent systems and activities that make up its BM and that must be considered in potential BMI for sustainability opportunities, the organization must take a holistic systems view (Level 4) to its operations, business model, and sustainability strategy. The framework of components – value proposition, value creation and delivery, and value capture – can then be used to structure environmental, social, and economic activities within the business model and position them for improved sustainability.

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Chapter 11
Closing the Loop: Industrial Ecology, Circular Economy and Material Flow Analysis

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Abstract This chapter explores the principles supporting industrial ecology (IE), circular economy (CE) and material flow analysis (MFA). IE concerns constructing industrial and societal processes according to ecological principles. One of the main features within IE is the principle of closing material loops by avoiding pollution. Insights from IE further aid in building the understanding essential for establishing the principles of circularity in the resource economy. MFA is viewed as an analytical method rooted in the field of IE and Systems Engineering (SE).

11.1 Industrial Ecology

According to Graedel (1996), Industrial Ecology (IE) should be defined as follows:

> Industrial ecology is the study of the means by which humanity can deliberately and rationally approach and maintain a desirable carrying capacity, given continued economic, cultural, and technological evolution. The concept requires that an industrial system be viewed not in isolation from its surrounding systems, but in concert with them. It is a systems view in which one seeks to optimize the total materials cycle from virgin material, to finished material, to component, to product, to obsolete product, and to ultimate disposal.

This definition is based on a systems' view and nature's carrying capacity. However, there are several definitions of IE (O'Rourke et al. 1996) which consider other objectives such as closed material cycles, evolutionary principles, resiliency, dynamic feedback, cooperation and competition in ecosystems. Industrial Ecology (IE) is the broad umbrella or the framework for thinking about and organizing production and consumption systems in ways that resemble natural ecosystems. This

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idea considers human societies to be part of and operate within natural ecosystems (Ehrenfeld 1994). The basic concept is to model industrial systems on natural ecosystems. IE aims to interpret and adopt an understanding of the natural system and apply it to the design of the man-made system to achieve a pattern of industrialization that is more efficient and adjusted to the tolerances and characteristics of the natural system. The emphasis is on forms of technology that work with natural systems, not against them. In contrast to industrial production, the natural environment has evolved into an inherently sustainable, cyclical system over billions of years. IE aims to incorporate these cyclical patterns into sustainable designs for industrial production systems. A pattern of change is illustrated by Fig. 11.1 (Jelinski et al. 1992).

In the early phases of the industrial revolution, the potentially usable resources were significant, and the existence of life forms was minimally impacted by extraction or waste. This view of *unlimited resources* might be described as linear, that is, as one in which the flow of material from one stage to the next is independent of all other flows (Jelinski et al. 1992). A contrasting picture emerges with "limited resources" as an ecosystem view. In such a system, life forms become strongly interlinked and form the complex networks we know today. According to the growing resource scarcity, industrial systems will be increasingly put under pressure to evolve to move from linear to semi-cyclic modes of operation. The central domain of IE is depicted in Fig. 11.1 with four central nodes: the materials extractor or grower, the materials processor or manufacturer, the consumer, and the waste

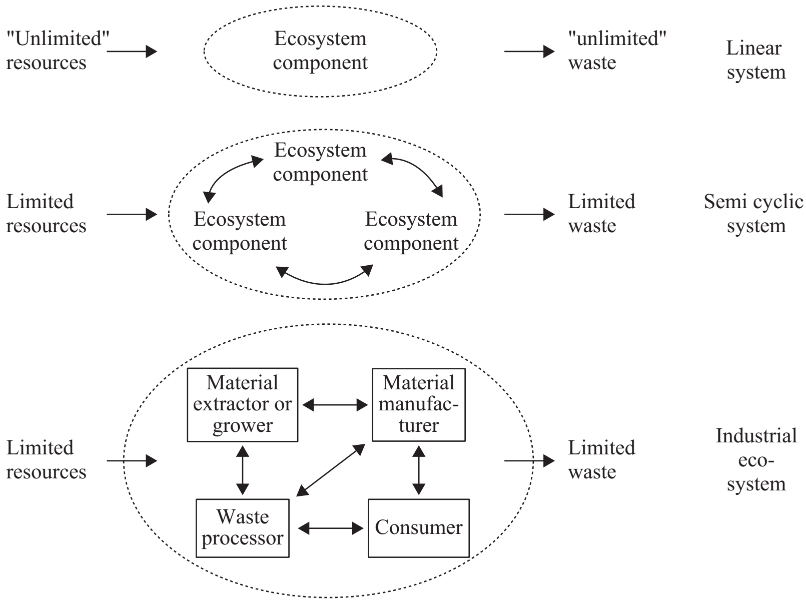

Fig. 11.1 The change from linear to cyclic material flows in the industrial ecosystem

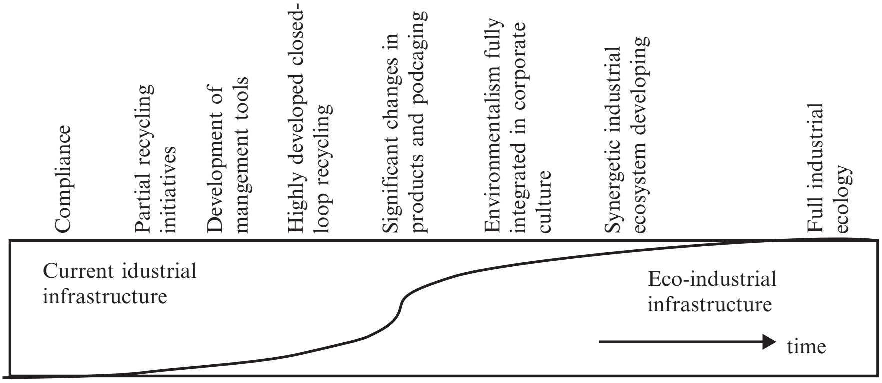

Fig. 11.2 The emergence of an eco-industrial infrastructure (Tibbs 1992)

processor. To the extent that they operate within the nodes in a cyclic manner or organise to encourage the cyclic flow of materials within the entire industrial ecosystem, they evolve into modes of operation that are more efficient and have a less disruptive impact on external support systems. Examples range from recycling of iron scrap by the heavy metals industry to the popularity of garage sales for the reuse of products in the consumer domain (Jelinski et al. 1992).

Applied IE embraces both business applications and technology opportunities (Tibbs 1992). It provides a basis for developing strategic options and policy decisions for those in management. Tools for analysis of the interface between industry and the environment is needed (Fet 2002). On the technical side, IE offers specific engineering and operational programmes for data gathering, technology deployment and product design. The technologies of real-time environmental monitoring are becoming increasingly sophisticated and must be integrated using information technology as a practical tool for mapping and managing environmental impacts. According to Tibbs (1992), process and product design should reflect IE thinking from initial design principles to final decommissioning and disassembly. The emergence of an eco-industrial infrastructure is illustrated by Fig. 11.2, which shows a set of shifts, both technological and institutional. With the goal of bringing industrial development into balance with natural and social systems, the two main objectives are to *achieve closed material cycles* and *realize a fundamental paradigm shift in our thinking about industry-environment relations* (O'Rourke et al. 1996). The first is an urgent goal. Unless product and material cycles are closed, the industrial system will continue to be unsustainable. Regarding the second goal, technology alone cannot achieve the transformation. It must therefore work within societal systems. The fundamental point is that implementation of IE, and over time, migration towards sustainable development will involve significant cultural, societal, and political changes. Resolving these conflicts requires fundamental change to our system of economics. (Tibbs 1992).

11.2 Implementing Industrial Ecology Principles in Business

Implementing IE principles into business practice requires simple rules, such as pollution prevention and material cascading. Material cascading means that waste from one company should be regarded as a resource for another company, which considers waste minimization, resource and energy efficiency and recycling opportunities. Pollution prevention includes re-designing products and processes where efforts like phasing out toxic materials emissions of persistent synthetic materials are essential. Raw material extraction should be reduced, the material should be selected and used with respect to the product life cycle, and material flows should be optimized concerning natural material cycles (Jackson 1993). IE is grounded in holistic life cycle system understanding. Ehrenfeld (1994) presented a list (based on Tibbs 1992) of the seven components of IE which should be considered when implementing IE principles in industry. A modifed version of the list of components is presented in Table 11.1).

The words which are written in cursive are used to highlight the critical issues within each of the categories. Adopting these in business practice relies on the incentives, competence, and willingness to change. In short, it can be said that the implementation of IE principles is about understanding ecological principles on one hand and understanding the interactions between business activity and the impacts on ecological systems on the other.

When implementing IE, process optimization comes first. Integration and coordination between firms are typically a prerequisite and closed-loop systems mean material reuse and recycling within a firm and material and energy cascading between firms. The industry parks Kahlundborg in Denmark and Nova Scotia in Canada are used to demonstrate IE in practice in a special set of relationships known as Industrial Symbiosis (Doménech and Davies 2011).

Table 11.1 Principal characteristics of industrial ecology

	Category
1:	Balancing industrial input and output to natural *ecosystem capacity*, hereunder identifying ways that industry can safely interface with nature in a holistic life cycle perspective.
2:	*Dematerialization* of industrial output, hereunder striving to decrease materials and energy intensity in industrial production.
3:	Creating *loop-closing* industrial practices, hereunder improving the efficiency of industrial processes by re-designing production processes and products for maximum conservation of resources.
4:	Improving *metabolic* pathways for materials use and industrial processes, hereunder create industrial ecosystems by fostering cooperation among various industries whereby the waste of one production process becomes the feedstock for another.
5:	*Systematizing* patterns of energy use, hereunder development of renewable energy supplies for industrial production, and creating energy system that functions as an integral part of industrial ecosystems.
6:	*Aligning policy* to conform with long term industrial system evolution, hereunder adoption of new national and international economic development policies

Modified after Ehrenfeld (1994)

However, there are omissions and weaknesses within IE. Policies often do not support goals, and analyses regarding the problems in changing current industrial practices, are often lacking. One major problem IE is facing is securing safe, clean, abundant alternatives to fossil fuels. Energy flow must remain open in any closed material cycle since energy cannot be recycled. It is of paramount importance, therefore, to switch to renewable energy sources whenever possible. This is not merely a technical issue: it requires structural societal changes such as governments putting forward policies for increasing the use of renewable energy and acceptance and the support of those policies by stakeholders as well as the public.

11.3 Closing the Loop: Circular Economy

The six principal characteristics of Industrial Ecology are presented in Table 11.1. The development of IE has also resulted in the emergence of new concepts such as green engineering, design for sustainability, eco-design, eco-industrial network and the Circular Economy (CE). CE gained traction in policy, business and academia and advocates the transformation of industrial systems from a traditional linear *take-make-dispose* model toward a circular model in which waste is a resource that is valorized through recycling and reuse (Geissdoerfer et al. 2017). For the business sector, three elements of CE provide a suitable means to operationalize sustainable industrial practices as they:

- increase the efficiency of resource utilization, thereby improving competitiveness and profitability (OECD 2021)
- provide an alternative to economic development models (Kirchherr et al. 2017)
- promote environmentally friendly use of resources (MacArthur 2013)

Figure 11.2 shows how elements of IE can be reflected in conceptualizing CE and its relevance to the business firms through production, use and end-of-life management strategies for their products. It illustrates the different elements of a circular economy, and where in the life cycle these should be addressed.

The theory from IE contributes to CE in different ways. According to Saavedra et al. (2018), this contribution can be structured along three levels:

1. Conceptual contribution
2. Technical contribution
3. Political and standard contribution

The conceptual contribution is related to category 4 in Table 11.1 where CE aligns with industrial symbioses (IS), which involves the exchange of by-products and wastes in planned complexes of co-located manufacturing plants thereby increasing the intensity of resource use by adding value from the same initial inputs. The technical contribution concerns the use of IE tools as presented in the CapSEM Model to support CE. According to Saavedra et al. (2018), the most commonly used tools are MFA, Design for the Environment (DfE) and Cleaner Production (CP).

However, CE can be linked to all Levels presented in the CapSEM Model (see Table 2.1 in Chap. 2, Part I of this book). If a product is designed favouring recycling combined with economic incentives, the potential to close material loops is high. The political and standard contribution is manifested in the application of IE to support the development of policies, laws, and standards to implement CE. To achieve this systematic transition towards a CE at a macro level, the collaboration of the business community, policymakers and institutions is fundamental, as intented by SDG number 17, 'Partnership'. Some policy instruments can be applied in this broader context of CE, such as regulatory instruments, research and educational instruments, technology transfer and informational instruments (e.g., eco-labelling).

There are numerous models for the circular economy. The circular economy system diagram, known as the butterfly diagram, see Fig. 11.3, is often employed (MacArthur 2013). Two principle cycles, technical and biological are used to demonstrate the continuous flow of materials in the economy. In the first, the way in which products are retained in circulation in the economy is by reusing, repairing, remanufacturing and recycling them. Materials are thus constantly used and never become waste. In the second, nutrients from biodegradable materials are returned to the Earth, through composting or anaerobic digestion. This permits the land to regenerate. The cycle then continues (MacArthur 2013).

Although there have been several attempts to define the scope of CE, critics claim that it is interpreted differently by different people. Kirchherr et al. (2017)

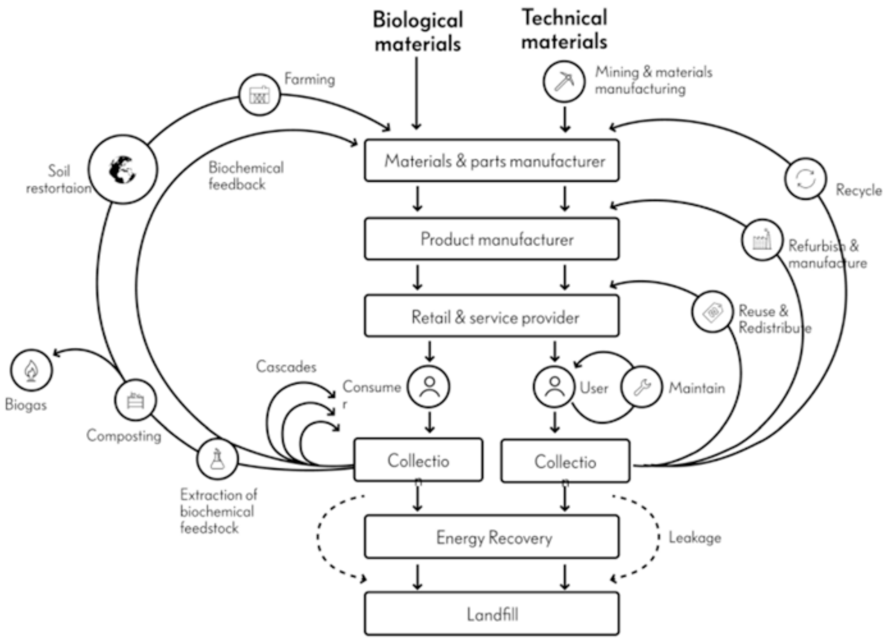

Fig. 11.3 The butterfly diagram: visualising the circular economy (ellenmacarthurfoundation.org, 2013)

report that more than 100 different definitions of circular economy are found in scientific literature. The definitions are often linked to the author's discipline which can render them confusing for researchers outside the discipline. According to Murray et al. (2017), the uses of the words *circular* and *linear*, in association with the word *economy* are potentially confusing as both links exist in entirely different contexts. While CE has been linked closely to IE and the environmental dimension of sustainability in this chapter, reflections on the social dimension have been less visible. So, for the implementation of CE in business, the social value should also be visible to avoid oversimplification of the concept. Considering these issues, Murray et al. (2017) have suggested the following definition:

> The Circular Economy is an economic model wherein planning, resourcing, procurement, production and reprocessing are designed and managed, as both process and output, to maximize ecosystem functioning and human well-being.

11.4 Material Flow Analysis

Material Flow Analysis (MFA) studies the physical flows of natural resources and materials into, through and out of a given system. It is based on methodically organised accounts in physical units. It uses the principle of mass balancing to analyze the relationships between material flows (including energy), human activities (including economic and trade developments) and environmental changes (OECD 2008). The basic principle of MFA simply applies the law of conservation of energy and mass: *matter is neither created nor destroyed*. MFA exemplifies what this law means in practice and how practitioners can demonstrate the law of conservation in solving real-life problems with varying degrees of complexity related to environmental management. The roots of MFA also lie in the material balance calculations in chemical engineering problems. Material balance is simply accounting for material, and it is often compared to the balancing of financial accounts. Money is deposited and withdrawn. The difference between these transactions at the end of the fixed time is accumulation in the account, also called the *Stock* in MFA terminologies. Because of the law of conservation of matter, the results of an MFA can be controlled by a simple material balance comparing all inputs, stocks, and outputs of a process. This distinct characteristic of MFA makes the method attractive as a decision-support tool in resource management, waste management, and environmental management (Brunner and Rechberger 2016).

11.4.1 MFA Methodology

MFA can be used for assessing various systems or scenarios. The terms *material* or *substance flow analysis* (MFA or SFA) are used interchangeably in the literature depending on the study unit, material or substance. MFA can be classified either by material type, analytical scope, chemical ingredient, or research purpose, providing

Table 11.2 Essential terminology in MFA studies

Term	Definition
Material	Material stands for both substances and goods
Substance	In chemistry, a substance is defined as a single type of matter consisting of uniform units.
Goods	Goods are substances or mixtures of substances that have economic values assigned by markets.
Process	A process is defined as the transport, transformation, or storage of materials.
Stock	Stocks are defined as material reservoirs (mass) within the analyzed system, and they have the physical unit of kilograms. A stock is part of a process comprising the mass that is stored within the process.
Flow and flux	Processes are linked by flows (mass per time) or fluxes (mass per time and cross-section) of materials. Flows/fluxes across systems boundaries are called imports or exports. Flows/fluxes of materials entering a process are named inputs, while those exiting is called outputs
System	A system comprises a set of material flows, stocks, and processes within a defined boundary
System boundary	The system boundary is defined in space and time. It can consist of geographical borders (region) or virtual limits (e.g., private households, including processes serving the private household such as transportation, waste collection, and sewer system)
Substance flow analysis (SFA)	Substance flow analysis (SFA) monitor flows of specific substances (e.g. Cd, Pb, Zn, Hg, N, P, CO2, CFC) that are known for raising particular concerns as regards the environmental and health risks associated with their production and consumption (OECD 2008).
Material system analysis (MSA)	Material system analysis (MSA) is based on material-specific flow accounts. It focuses on selected raw materials or semi-finished goods at various Levels of detail and application (e.g., cement, paper, iron and steel, copper, plastics, timber, water) and considers life-cycle-wide inputs and outputs. It applies to materials that raise particular concerns as to the sustainability of their use, the security of their supply to the economy, and/or the environmental consequences of their production and consumption. (OECD 2008)

Modi fied from Brunner and Rechberger (2016)

the potential to assess sustainability from various analytical perspectives. Before exploring the methodological steps, it is essential to understand the terminology used in describing the MFA study. Table 11.2 provides a brief overview of all the critical terms for an MFA study.

Figure 11.4 demonstrates the typical system flow diagram for MFA for a system. P1 and P2 are processes, and S1 is the stock within P1 where the material is accumulated. Here, $A_{0,1}$, $A_{1,2}$, $A_{2,1}$ and $A_{2,0}$ are the flows from which material and substance enter the system. As per the definition of a process, the material is either transformed, transferred or stored in the process represented by boxes.

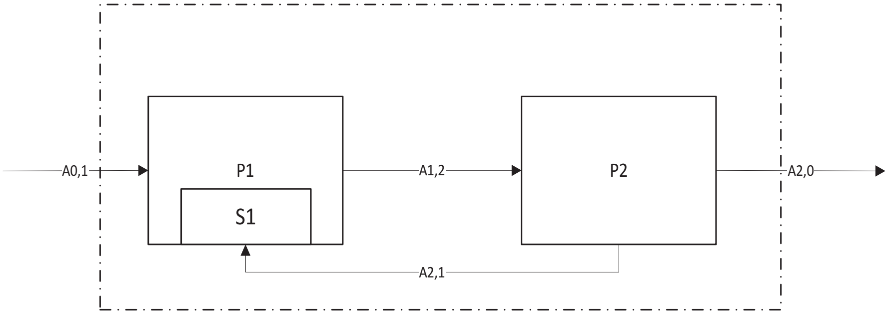

Fig. 11.4 Typical process flow diagram for the MFA system

According to the law of conservation of matter, the mass balance equations for each process can be represented as follows:

$$\sum Input\ flows = \sum Output\ flows + \sum Stocks$$

$$Change\ in\ Stock\ \frac{\Delta S1}{\Delta t} = A_{0,1} + A_{2,1} - A_{1,2}$$

$$Mass\ balance\ for\ Process\ P2: A_{1,2} - A_{2,1} - A_{2,0} = 0$$

If inputs and outputs do not balance when mapping the MFA system, then one or several flows are either missing or have been wrongly calculated. The mass-balance principle applies to systems, sub-systems and processes. An accurate material balance of a system or a process is only achieved if all input and output flows are known or measured. In practice, stocks are often calculated by the difference between inputs and outputs. All the necessary information for calculating material flows should be available from a variety of sources such as company records, national reports, statistical databases, and published scientific literature. In some instances, relevant stakeholders and resource users can be targeted to gain insights into the system to be studied (Deshpande et al. 2020). After calculating all the flows, the mass balance of the system needs to be checked, and uncertainties of the obtained information need to be evaluated. MFA studies involving several flows, processes and stocks tend to become complicated. Dividing processes into sub-processes, re-adjusting system boundaries or using analytical software for calculations are the few techniques to approach the complicated MFA systems. Brunner and Rechberger (2016) describe calculations protocols, uncertainty analysis, and various software packages available for conducting MFA in their ‘Practical Handbook of Material Flow Analysis’.

Table 11.3 Type and application of MFA, based on objectives of interest

Specific environmental problems related to certain impacts per unit flow of:		
Ia	**Ib**	**Ic**
Substance	*Materials*	*Products*
e.g., Cd, Cl, Pb, Zn, Hg, N, P, C, CO_2, CFC	e.g., wooden products, energy carriers, excavation, biomass, plastics	e.g., diapers, batteries cars
Problems of environmental concern related to the throughput of:		
IIa	**IIb**	**IIc**
Firms/industry	*Sector*	*Region*
e.g., single plants, medium and large companies	e.g., production sectors, chemical industry, construction	e.g., total or main throughput mass flow balance, total material requirement

11.4.2 MFA Applications

An MFA delivers a complete and consistent set of information about all flows and stocks of a particular material within a system. The depletion or accumulation of material stocks is identified early enough to take countermeasures or promote further build-up and future utilization. Moreover, minor changes that are too small to be measured in short time scales but could slowly lead to long-term damage also become evident. Historically, MFA is applied through various scales from a global or national level to a company, product, and process level. In general, MFA provides a system-analytical view of various interlinked processes and flows to support the strategic and priority-oriented design of management measures. Table 11.3 presents the overview of MFA connecting to the application at various levels, i.e., substance (Ia), materials (Ib), and products (Ic) (Bringezu et al. 1997). These refer to Levels 1 and 2 in the CapSEM Model. The CapSEM model suggests that MFA at Level 1 is accounted for by each production process's inputs and outputs (I/O). The accounting embraces both substances and other materials, as shown in Table 11.3. Similarly, for products viewed in a life cycle perspective. This is noted under Ic in the table. Levels 3 and 4 in the CapSEM model are represented by firms (IIa), sectors (IIb), and regions (IIc) in Table 11.3. The firm-level MFAs help realize sustainability goals by uncovering major problems existing in the production phase and across the product life cycle, supporting priority setting, checking the possibilities for improvement measures, and providing tools for monitoring their effectiveness.

The environmental performance indicators (EPIs) assessed through MFA studies, complement the sustainability reporting and other tools used to assess the firm's environmental performance management through tools such as input-output analyses and life cycle assessment (LCA). The insights gained through applying MFAs within industries helps in designing corporate strategies for regulatory compliance, resource conservation, and waste management, waste prevention or circular economy.

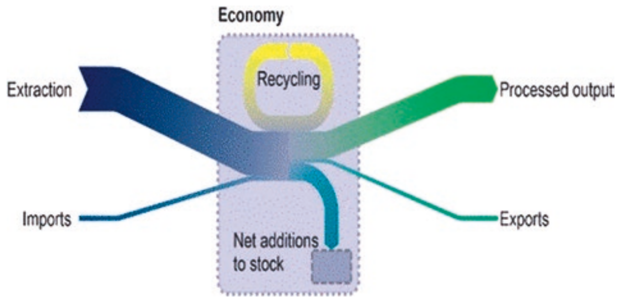

Fig. 11.5 Representative illustration of MFA through Sankey diagram (Schmidt 2008a, b)

Historically, MFA has been used for a wide range and scale of applications. Binder (2007) classifies the applications of MFA between industrial and regional scale analysis. MFA results have successfully been used to optimize material flows and waste streams in production. MFA is a central methodology used within industrial ecology and quantifies how the materials that enable modern society are used, reused and lost (Bringezu S and Moriguchi Y 2002). Sankey diagrams named the 'visible language of industrial ecology', are often employed to present MFA results, see Fig. 11.5. Such a model exemplifies a mass balance between extracting natural resources and importing goods or resources, with outputs represented as exported goods, and other processed outputs. Differences between inputs and outputs become additions to national reserves. Recycling guarantees the retention of these elements within the national economy which is consistent with the definition of a circular economy.

Moreover, industrial eco-parks are based on optimizing material flows within different industry sectors, which can be assessed using MFA (Chertow 2000). On a regional scale, MFA results could be applied to derive measures for improving regional, or corporate, management of materials: to optimize resource exploitation, consumption, and environmental protection within the particular constraints of the region or company (Binder 2007).

11.5 Conclusion

MFA approaches are now being linked with environmental input-output assessment, life cycle assessment and scenario development. These increasingly comprehensive assessments promise to be central tools for future sustainable development and circular economy studies (Graedal 2019). Industrial Metabolism (IM) and Industrial Symbioses (IS) are also more often referred to in studies of applied IE (Oughton et al. 2022). This chapter has assessed the history and status of MFA, reviewed the development of the methodology, and demonstrated that MFAs have been responsible for creating related industrial ecology specialities and stimulating connections between industrial ecology and a variety of engineering and social science fields. Closing the loop for the preservation of scarce planetary resources requires the collaborative efforts of participants at all levels of society. An idealized end-state has been loosely described as a circular economy. The CapSEM Model offers both a transition pathway and specific methods to achieve this objective.

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Chapter 12
Systems Engineering

Annik Magerholm Fet and Cecilia Haskins

Abstract The value of systems science approaches to address sustainability topics has been formally recognized since the publication of *Limits to Growth* (1972) and the application of system dynamics to investigate the synergies between planetary activities. Since then, these methods have been applied to address the chaos and reverse the consequences of the anthropomorphous influences at the root of today's wicked problems – climate change, species extinction, unbalanced social equity. Systems engineering provides theory and practices that are both systemic, systematic, sustainable, and based on the foundations of systems science.

12.1 Background

The purpose of this chapter is to describe the use of systems thinking and systems engineering for the purpose of addressing and working with sustainability challenges, dealing mainly with society-business interactions. Readers should note that the methods presented in the CapSEM Model (Part I, Chap. 2) focus mainly on environmental aspects of sustainability. Systems engineering provides a framework to fully consider the needs of stakeholders and other social and economic aspects (Fet and Knudson 2021).

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12.1.1 Definitions

Systems engineering (SE) is recommended as an approach to incorporate stakeholder needs and participation in the transition to sustainable and environmental management. SE is both a discipline and a process. As a discipline, SE concerns adopting a holistic life cycle perspective and constantly evolving to bring in aspects from other disciplines when needed. SE as a process is a *transdisciplinary and integrative approach* to enable the successful realization, use, and retirement of engineered systems – both technological and social, by using systems principles and concepts, and scientific, technological, and management methods (Sillitto et al. 2019). The *transdisciplinary approach* organises the analysis and decision-making around common purpose, shared understanding and 'learning together' in the context of real-world problems or themes. It is usable at any CapSEM Level, from simple to complex, and is especially necessary in unprecedented situations or where there exists a significant degree of complexity. An *integrative approach* by itself can be adequate where the situation is not overly complex or when dealing with a situation that has been encountered before and a path to the solution can be readily identified and understood (albeit there will still be many challenges along the way, technical and otherwise). Systems principles and concepts are the ways in which systems thinking and the systems sciences provide a foundation for systems engineering practices. Examples of some of the principles, concepts and supporting tools are mental models, system archetypes, holistic thinking, separation of concerns, abstraction, modularity and encapsulation, causal loop diagrams, systemigrams, and systems mapping. The Systems Engineering Body of Knowledge (SEBOK 2021) describes many of these: it also provides an extensive reading list.

12.1.2 SE Practices

Two concepts are essential to understanding the broad scope of systems engineering. The first, systematic, means taking a thorough, orderly approach to solving a problem or set of problems. The second is the systemic perspective. The term means taking a holistic appreciation of the topic under consideration, whether a man-made engineered system or an international political effort toward reduction of climate gases emissions. The literature of systems engineering practice describes a variety of systematic processes for developing, designing, and deploying large-scale complex systems, such as the standard for systems engineering life cycle development ISO/IEC/IEEE 15288: 2015. At the same time, successful systems engineering must be built on a foundation of systemic thinking to conceive and solve complex problems (Hitchins 2007).

Systems engineering can be used as a management technology to assist and support policy making, planning, decision making, and associated resource allocation or action deployment. All systems engineering may be thought of as consisting of formulation, analysis and interpretation of the various elements in all phases of the life cycle of a system. Both top-down and bottom-up approaches are needed and used in SE practices. The top-down approach is primarily concerned with long-term issues that concern structure and architecture of the overall system and is useful in planning phase when the system must be viewed as a whole, as at CapSEM Level 4. The bottom-up approach is concerned with making parts of the system more efficient and effective so they can be incorporated into the overall system and is useful when determining the tasks to support operational decisions, as in CapSEM Levels 1–3 (Fet and Knudson 2021).

12.2 Description

Systems engineering as a process to support planning, decision-making and system design has been described in many ways to address the unique needs of a given situation or domain. Fet (1997) devised a generic process that encompasses the essential activities of the SE development life cycle process. This 6-step model is provided in Fig. 12.1 and is the basis for the mapping to relevant CapSEM methods presented in Fig. 12.1.

Step 1: Identify Needs
In this step, the stakeholders' needs, their values and concerns are identified. It includes an iterative loop where the statement of needs answers the question *What is needed?* The logic is an answer to the question *Why is it needed?* and the search for preconceived (technical) solutions answers the question *How may the need be satisfied?* The *statement of need* should be presented in specific qualitative and quantitative terms, in enough detail to justify progression to next step.

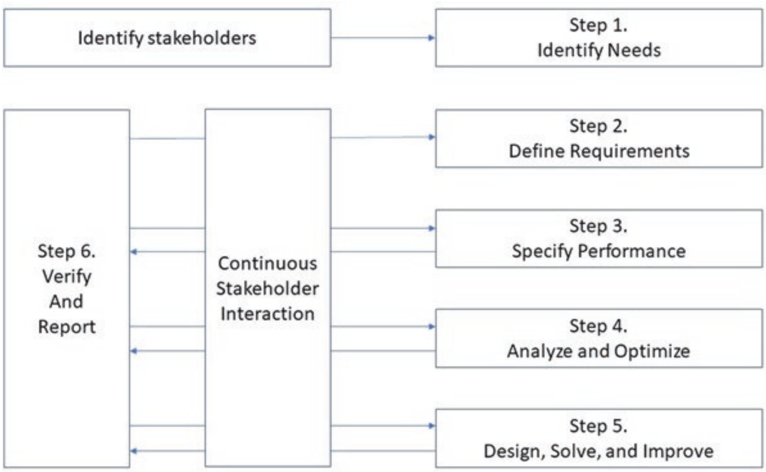

Fig. 12.1 Systems engineering life cycle process, 6-step framework

Step 2: Define Requirements

After identifying stakeholders' needs, attention turns to defining requirements that describe how the system is supposed to be designed, function and be operated during the life cycle. Both functional, operational and physical performance requirements should therefore be defined. While functional requirements reflect the system's ability to carry out functions and should be an answer to the *what* in step 1. Operational requirements are related to the operation of the system all in a life cycle perspective, and an answer to the *why* in step 1. The physical requirements reflect the physical conditions the system will be exposed to, and how the system interacts with the environment, and thereby an answer to the *how* in step 1. The definition of functional, operational and physical performance requirements must be set to each of the integrated parts of a system, both to the hardware, software, bioware and the economic parts, which together describe a system (Fet 1997).

Since the toolbox in the CapSEM Model mostly concentrate on the environmental issues of sustainability, the defined requirements should also take a specific role in meeting the performance requirements for achieving the change in performance as was illustrated in Fig. 2.1 in this book. By identifying relevant SDGs that points to the actual CapSEM-levels as shown in Fig. 3.2, the underlying targets can be helpful when specifying the necessary performance requirements to meet the stated needs under step 1.

Step 3: Performance

As soon as the system requirements are defined, they should be translated to performance specifications, i.e. definable and measurable performance criteria. The specification of performance should be formulated by means of performance indicators, for example, OPIs, MPIs and KPIs, and reflect the needs and requirements formulated in Steps 1 and 2, and also help to answer *What*, *Why* and *How*.

The functional analysis should be performed as an iterative process to ensure that all elements of system design and development, production, operation, and demolition and support are covered in the performance specification. The performance should be specified in a way that measurements verify that needs and requirements are met. Quantification of the performance indicators selected in step 3 are further analyzed using impact assessment methods and other various tools suggested in the CapSEM Model such as life cycle assessment (LCA) and material flow analysis (MFA) (Valenzuela-Venegas et al. 2016).

Step 4: Analyze and Optimize

System analysis includes an analytical process of evaluating various system design alternatives. This is called a *trade-off* which may be defined as "a compromise between conflicting interest with the need to maintain equilibrium" (Rolstadås 1995). This step includes activities such as searching for a configuration, principles and technologies to meet specifications conceptually, selection or discrimination between system alternatives, and optimizing by the trade-off analysis. Trade-offs between many, often conflicting system requirements, should be carried out, and this analysis of the system and the specification of its performance goes into an iterative loop of improvements.

The problem is to select the best approach possible through the iterative process of system analysis using various analytical methods. The use of weight factors based upon the priorities of stakeholders is an important part of the analysis (Freeman 2010). Different optimization techniques should be used.

The trade-off therefore needs to meet a few requirements itself. These may be:

- Define the objective function for the total system performance evaluation
- Define the conditions under which the system performance is to be measured
- Establish the measurement/evaluation criteria for a 'best' satisfaction of the functional, operational and physical needs and requirements.

In the optimization phase it is important to select objective functions taking all alternatives into account. The general purpose of an objective function is to express in quantitative form a total single measure of the system performance. Performing the analyses, optimisation and evaluation is again an iterative process and should be performed until a design (or suggestion to the solution of the problem) is accepted.

Step 5: Design, Solve and Improve
Based on the preliminary system design or suggestion of solutions, a detailed design phase begins derived from the preliminary needs through system requirements and performance specifications, synthesis and analysis. When the overall system definition has been established in an accepted conceptual solution, it is necessary to progress through further definitions leading to the realization of hardware, software, bioware and economics, all seen in relation to their possible environmental impacts throughout the system's life cycle. Decision-makers should make the final decision on which changes to implement. Where multiple strategies exist, decision-makers may use multi-criteria appraisals to identify preferred strategies based on the stakeholders' subjective preferences with reference back to stated needs and requirements.

Step 6: Verify and Report
The final step of the process concerns monitoring and recording the performance of the selected course of action. The iteration between steps 4 and 5 should provide the information and data needed to continuously evaluating the current strategies and come up with solutions for improvements and changes to the actual CapSEM Levels.

12.3 Application

Progress toward environmental and sustainability performance improvements at different system levels is encapsulated in *human activity systems*. The term refers to social systems where the intentional agents are humans, working toward a common purpose and where the social system is deliberately constructed and maintained and can adapt rapidly. A major goal of Systems Engineering is to reduce the risk that accompanies such systems by establishing shared and valid models of the system, in order to improve stakeholders' knowledge and understanding of the system and its context. To quote Forrester, the inventor of System Dynamics,

> We do not live in a unidirectional world in which a problem leads to an action that leads to a solution. Instead, we live in an on-going circular environment. Each action is based on current conditions, such actions affect future conditions, and changed conditions become the basis for later action. There is no beginning or end to the process (Forrester 1998).

12.3.1 Systems Approach for Capacity Planning

In his insightful article on how capacity planners can benefit from systems thinking, Hauck (2005) offers the following five insights:

- Cause and effect relationships are not always linear; they are frequently delayed in time and unpredictable
- Many successful systems have evolved through incremental adaptations
- Many capacity development processes do not have measurable objectives, but are guided by implicit intentions and ideas that adjust to emerging situations
- Interconnections among the components of a system are important and can give rise to valuable synergies
- Feedback is critical for learning and self-awareness, but the form it takes is culturally determined and cannot be applied in a standardized manner.

These insights are relevant to decision-making throughout the entire life cycle of a system and can be applied from decisions at Level 1 and at each subsequent level of the CapSEM Model. Systems approaches such as these have become standard practice for monitoring progress of the current UN sustainable development goals (Selomane et al. 2019; Haskins 2021). Levels 1 and 2 concern technical analysis. Levels 3 and 4 mainly concern human decisions between people, technology and an organization.

12.3.2 Systems Engineering applied to the CapSEM Model

To illustrate the usefulness of SE as a framework for choosing methods for implementing the CapSEM Model approaches to sustainability, Fig. 12.2 maps the basic SE process in the left column to the activities and outcomes for the recommended methods including Level 1, represented by cleaner production (CP), Level 2, represented by life cycle assessment (LCA) and design for the environment (DfE), Level 3, represented by environmental management systems (EMS) and environmental performance evaluation (EPE).

The application of SE practices to a given CapSEM method also requires attention to the topic of system boundaries (step 1), which occur between (1) the system under study and the environment, (2) the system under study and other interrelated systems, and (3) relevant and irrelevant processes (Selomane et al. 2019). Material, energy and information crossing the boundaries are defined as inputs to or outputs

Systems engineering (SE)	Cleaner production (CP)	Life cycle assessment (LCA)	Design for environment (DfE)	Environmental management systems (EMS)	Environmental performance evaluation (EPE)
1. Identify needs	1. Planning and organising	1. Goal and scope definition	1. Needs analysis	1. Environmental policy	1. Commitment
2. Define requirements			2. Requirements	2. Initial planning	2. Planning
3. Specify performance	2. Assessment and preparation	2. Inventory analysis		3. Planning 4. Implementation and operation 5. Checking and corrective action	3. Applying
4. Analyse and optimise	3. Assessment step 4. Feasibility analysis step	3. Impact assessment 4. Interpretation	3. Life cycle strategies and evaluation		
5. Design, solve and improve	5. Reporting 6. Implementation	Application of LCA results	4. Design		4. Reviewing 5. Improving
6. Verify and report			5. Implement	6. Management review 7. Documentation 8. Registration	

Fig. 12.2 Mapping of systems engineering processes to CapSEM Model methods and tools (Fet 2002)

from the system. As part of an environmental analysis, the environmental loads are determined by materials extracted from natural resources and emissions into the environment, all of which cross defined system boundaries. Processes often generate different products, byproducts and functions, in co-production, recycling or waste processing. System interactions should be classified according to which of the interrelated systems belong to the system under study, and which do not. Only after selecting the most appropriate system boundaries can the decision be taken of how the scope of a given study of a system should be extended.

12.3.3 Systems Engineering as an Integrating Framework

The eventual application of SE in any CapSEM Level relies on integrated practices as recommended by Asbjørnsen (1992). A system should be viewed as a combination of some or all of four different disciplines of roughly equal importance:

- the disciplines of technology that include the physical equipment (Hardware),
- the disciplines of financial science that include the monetary aspects (Economics),
- the disciplines of information science that include computer applications (Software),
- the disciplines of social science that include human factors and psychology (Bioware).

In this way, technology, management, legal aspects, social and environmental issues, finance and corporate strategies are all addressed by a total system integration and inter-disciplinary cooperation. Decisions made during the early phases of system development have a great impact on the total life cycle costs, as well as the life cycle environmental performance. Both the life cycle costs and the life cycle environmental performance should be balanced against the estimated improvement in performance and related to the overall purpose of the system. In addition, the processes and methods utilized in the acquisition of systems must be such that systems can be acquired in a timely and expeditious manner and designed and developed as effectively and efficiently as possible, considering the limitation of available resources. The resource requirements and the time requirement to carry out and complete the work must be specified early in order to ensure a proper allocation of resources, and to relate the work properly to the total time available, e.g., an upgrade to a manufacturing facility will desire the shortest possible downtime.

12.4 Systems Engineering as a Collaboration Framework

Sillitto et al. (2019) assert that SE is essentially collaborative in nature, facilitating collaboration between all contributors to system success, recognizing the need to respect diverse points of view. They suggest the following critical activities supported by SE practices (Sillitto et al. 2019).

- Defining and managing the interfaces, both within the system and between the system and the rest of the world (noting that increasingly, systems engineering is conducted in a brown-field rather than a greenfield environment, so legacy systems may be a major or key part of the overall solution);
- Establishing appropriate process and life cycle models that consider complexity, uncertainty, change and variety, and implementing system management and governance processes for both development and through-life use and disposal;
- Supporting transition to operations, considering all aspects including people, processes, information and technology;
- Periodically re-evaluating status, risks and opportunities, stakeholder feedback, observed or anticipated unintended consequences, and anticipated system effectiveness and value, and recommending any appropriate corrective, mitigation or recovery actions to ensure continuing system success.

These can include upgrading, obsolescence management, maintenance and repair activities, manufacturing changes, changing operational processes, user training, instituting metrics and incentives, assessing information quality and integrity, and making other changes to the system as suggested by the CapSEM Level and methods employed.

12.5 Conclusion

This brief introduction to SE gives an overview of systems engineering practices in regards to their position(s) on the CapSEM model, explaining the contribution of these activities and their relevance to all Levels of the model. The reader is encouraged to explore the references given here as a departure point for employing these methods.

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Part III
From Theory to Practice: Case Studies

Chapter 13
Introduction to the Case Studies

Annik Magerholm Fet

Abstract This chapter provides an introduction and summary of the seven Case Studies in Part III. The reason behind their inclusion is explained here and their relevance to the CapSEM Model highlighted. The emphasis is on continuous and ever evolving research in this area, including a Case Study (Chap. 18) which is deliberately longitudinal in nature. Transition towards sustainability is at the core of these studies, demonstrating that while the starting point may be the need for a remedial solution, the path to resolving such issues differs, is not linear and involves the application of different CapSEM Model Levels. Such problems are of global, not only local, interest. The Case Studies therefore provide a variety of roadmaps, rather than definitive or prescriptive guidance, which should prove of interest to industry and those examining how the CapSEM Model is put into practice.

The cases presented in Chaps. 14–20 are hand-picked from an inventory of research conducted by myself and my PhDs and my colleagues and students over many years, including some ongoing projects. In each instance, an initial problematic state within the boundaries of a specified organization, environment, or situation needed a remedial solution. However more often than not, the solution was a starting point for additional activity, in keeping with the concept of continuing improvement and transition toward sustainability. For this reason, each case study is more a roadmap than a prescription, and the problems addressed are global as much as they are local. The cases may revolve around a single, sectoral or regional issue using quantitative evidence from multiple sources, and building, when possible, from the results of previous research.

The cases share a number of features. For many in the industrial domain problems arise when customer or regulatory requirements shift toward products that meet stringent sustainability performance criteria (cf. Chaps. 14 and 18). Municipalities are driven by similar challenges to provide services that meet strict requirements imposed by their constituencies for responsible environmental

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Table 13.1 Cases categorized by industry and CapSEM Level

Chapter title	Industry	CapSEM Level(s)
Chapter 14: From *waste to value*: a story about life cycle management in the furniture industry by Ottar Michelsen, Christofer Skaar, Annik Magerholm Fet	Manufacturing furniture	1, 2, 3
Chapter 15: The role of public sector buyers: Influencing systemic change in the construction sector by Shannon Truloff, Luitzen de Boer, Xinlu Qiu and Annik Magerholm Fet.	Government acquisition	3, 4
Chapter 16: CapSEM applied to the construction sector by Magnus Sparrevik, Luitzen de Boer, Ottar Michelsen and Christofer Skaar	Construction	2, 3, 4
Chapter 17: Application of material flow analysis: mapping plastics within the fishing sector in Norway by Paritosh C Deshpande and Arron W. Tippett	Waste maritime	4
Chapter 18: Environmental Management at Fiskerstrand Verft AS: a 30 year journey by Rolf Fiskerstrand and Annik Magerholm Fet	Manufacturing shipyard	All
Chapter 19: A transportation planning decision support system by Dina Margrethe Aspen	Societal planning	4
Chapter 20: First steps towards sustainable waste management by Øystein Peder Ssolevåg	Waste management	All

stewardship (cf. Chaps. 15, 19 and 20). Industrial sectors such as construction (Chap. 16) and fishery (Chap. 17) struggle to coordinate the efforts of many actors toward desirable sustainable processes. In all cases, tools and methods from the CapSEM Model provide direction to improve and continuously transition to sustainable objective. Systems engineering and industrial ecology principles are applied in nearly every case. Table 13.1 categorizes the cases according to the industry and the CapSEM Level of application.

The following provides a quick synopsis of the cases that follow.

Chapter 14: From Waste to Value: A Story About Life Cycle Management in the Furniture Industry

This case focuses on the use of the CapSEM Model by the Norwegian furniture industry, beginning with efforts that raised sustainability awareness through a series of case studies over a period of more than 10 years. It started with a Cleaner Production (CP) programme for a group of furniture companies in a small community. The goal for another case study running in parallel with the CP-project, was to define a common set of Environmental Performance Indicators (EPIs) for reporting purposes for both the companies and the municipality to reduce waste and improve its treatment according to circular principles. While CP is at Level 1, EPIs and reporting is on level 3 and 4 in the CapSEM Model. In the furniture sector, the CP-programme led to capacity building by integrating Level 2 methods such as Life Cycle Assessment (LCA) into their daily work processes. LCA was used for product improvements based on hot spots detected through the analyses, and also to generate Environmental Performance Declarations (EPDs) for products. The implementation of these new procedures was integrated into the organisation's strategic work through certified Environmental Management System (EMS). In addition to a demonstration of a gradual shift from Levels 1, 2 and 3, the case also describes the benefits of building cooperative communities (Level 4) that include sectoral, regional, and academic participants. The Level 4 activities were originally initiated by a Norwegian Local Agenda 21 programme.

Chapter 15: The Role of Public Sector Buyers: Influencing Systemic Change in the Construction Sector
Construction machinery is essential to all construction projects and is also a significant contributor to both air pollution and greenhouse gas (GHG) emissions. The Non-Road Mobile Machinery Market (NRMM), otherwise known as the construction machinery market, largely operates using diesel fuel nowadays which has significant negative environmental impacts. It is critical that governmental leaders push suppliers to innovate and implement sustainable solutions in the construction sector. Green Public Procurement (GPP) and Innovation Orientated Public Procurement (IOPP) have emerged as potentially powerful instruments to drive green innovation by providing 'lead markets' for new technologies. City municipalities, regions, nations, and supranational government structures such as the European Union (EU) are starting to use public purchasing to achieve cleaner construction and Zero Emission Construction Sites (ZEMCONs). Early Market Dialogues (EMD) prior to the release of procurement documents can be an effective tool for achieving innovative solutions and for creating positive buyer and supplier collaboration. This case illustrates how the CapSEM Model and toolbox can operate from a top-down approach, initiating collaborative approaches amongst multiple actors, across multiple CapSEM Levels.

Chapter 16: CapSEM Applied to the Construction Sector
The construction sector and built environment have the potential to impact on a variety of systemic dimensions, ranging from specific processes in the production of construction materials to pan-national regulations affecting regional areas and cities. This case study uses the CapSEM Model in order to identify the potential enabling and constraining impact of different methods, schemes and regulations for reducing environmental impact in the construction sector. The use of a systemic perspective highlights that all methodologies are working recursively in actor-networks, thereby affecting society and the market differently, depending on the systemic level.

Chapter 17: Application of Material Flow Analysis: Mapping Plastics Within the Fishing Sector in Norway
Plastic in our marine environment is now ubiquitous. Abandoned lost or otherwise discarded fishing gear (ALDFG) is of particular concern due to its ability to continue to function as a trap for marine organisms. In order for decision makers to act on this grave issue, we require data on the flow of ALDFG into the marine environment. One key tool for revealing the flow of material within a specific system is

Material Flow Analysis (MFA). MFA takes a life cycle approach (cradle to grave) to assess energy or material flows in a system within space and time boundaries. It can be applied at multiple levels from the industrial process level to the national level. This chapter presents a case study of an MFA conducted on fishing gear in Norway. The MFA methodology was used in this case study to assess the flow of plastic fishing gear from production through to recycling, final disposal or loss to the marine environment. Data was collected for the MFA through stakeholder interviews, literature reviews and analysis of government data sets. The MFA revealed that around 4000 tons of plastic fishing gear enters the system in Norway and around 400 tons enter the marine environment each year. An analysis of the implications of the MFA for the key actors within the life cycle chain of fishing gear is presented and a short description of the links between MFA and the circular economy and sustainable development is provided. Furthermore, the relevance and implications of using MFA tool for policy making at national and regional level is discussed and elaborated while associated challenges are presented here.

Chapter 18: Environmental Management at Fiskerstrand Verft AS: A 30 Year Journey

Fiskerstrand Verft is a multipurpose shipyard with extensive expertise and activities in shipbuilding, maintenance, repair and conversion/modification of ships. The yard is exposed to a range of different environmental challenges related to its business which trigged the yard to develop and implement health and safety, and environmental management systems. This chapter gives an overview of environmental management at Fiskerstrand Verft over a 30-year period, written from the perspective of the first author as CEO. The activities from 1991 to 1994 mainly considered Level 1 in the CapSEM Model with annual accounting of materials and wastes, emissions to air and discharges to ocean. The yard participated in various R & D environmental projects and during the period 1994–1999 these were extended with activities corresponding to life cycle thinking according to Levels 2 and 3. In 1999, Fiskerstrand Verft was the first Norwegian shipyard that prepared and published an environmental report. The yard was certified as an environmental lighthouse company in 2000, the first in Norway. During the period 2004–2008, the yard further developed their systems and began to transition to Level 4. The life cycle perspective for ships and technology has been at the center of the development of green technologies for ships. This journey continues today, passing the 30 year mark, and has contributed invaluable knowledge about the CapSEM toolbox and how it can be applied to shipyard operations.

Chapter 19: A Transportation Planning Decision Support System

In this chapter, the CapSEM toolbox is explored, applied and evaluated in the context of transportation planning and policy making. Transportation system elements are analyzed across all four CapSEM levels to identify relevant tools to utilize in decision support systems to address sustainability in the sector. The application of the toolbox is demonstrated through a transportation planning case study. Benefits observed from the application include (i) a useful framework to decompose and stack models across system and performance levels to handle transportation modeling complexity, and (ii) an approach to engage and interact with stakeholders and decision-makers through problem structuring, modeling, analysis and resolution.

Chapter 20: First Steps Towards Sustainable Waste Management
Waste management started off as a public health issue. Today, the waste business is an important force in developing sustainable development and circular economy. New policies and regulations represent an opportunity for circularity, but there is still a long way to go in achieving a truly circular economy. The Circularity Gap Report 2020 indicated that the global economy is only 8.6% circular. Industrial ecology and material flow analysis are important tools, not only for developing local and regional waste solutions, but also in the development of new global circular business models. In the Ålesund region, new sorting measures have increased recycling, from 32% in 2017 to 45% in 2019. New measures will be needed to reach national targets set for 2025. As the current global use of resources is unsustainable, and as current waste business models are insufficient to achieve circular economy, the next decade is likely to experience a rapid innovation of new business models challenging traditional waste management companies. This chapter presents data collected during a case study conducted in 2020.

13.1 Concluding Remarks

The inclusion of these Case Studies is crucial to being able to demonstrate the CapSEM Model in action. They have been carefully chosen in order to show that the trajectory for a transition to sustainability is not necessarily linear, nor will each company or industry take a similar length of time to achieve their objectives. It also exemplifies the flexibility of the model and how continuous improvement is very much part of this circular approach to development within any given sector or business. In turn, this can feed back into the development of the CapSEM Model itself and its future use.

Chapter 14
From *Waste to Value*: A Story About Life Cycle Management in the Furniture Industry

Ottar Michelsen, Christofer Skaar, and Annik Magerholm Fet

Abstract This case focuses on the use of the CapSEM Model by the Norwegian furniture industry, beginning with efforts that raised sustainability awareness through a series of case studies over a period of more than 10 years. It started with a Cleaner Production (CP) programme for a group of furniture companies in a small community. The goal for another case study running in parallel with the CP-project, was to define a common set of Environmental Performance Indicators (EPIs) for reporting purposes for both the companies and the municipality to reduce waste and improve its treatment according to circular principles. While CP is at Level 1, EPIs and reporting is on level 3 and 4 in the CapSEM Model. In the furniture sector, the CP-programme led to capacity building by integrating Level 2 methods such as Life Cycle Assessment (LCA) into their daily work processes. LCA was used for product improvements based on hot spots detected through the analyses, and also to generate Environmental Performance Declarations (EPDs) for products. The implementation of these new procedures was integrated into the organisation's strategic work through certified Environmental Management System (EMS). In addition to a demonstration of a gradual shift from Levels 1, 2 and 3, the case also describes the benefits of building cooperative communities (Level 4) that include sectoral, regional, and academic participants. The Level 4 activities were originally initiated by a Norwegian Local Agenda 21 programme.

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14.1 Introduction

Small and medium sized enterprises (SMEs) are often neglected in studies on industrial impacts on the environment (von Geibler et al. 2004), despite the considerable overall environmental impact from SMEs. One challenge facing these companies is limited resources and knowledge, which is also often not prioritized since they tend to perceive their own contribution as negligible in the absence of any prior quantification (Ammenberg and Hjelm 2003). However, this is about to change with increasing demands for documentation on both company and product environmental data and information from society and the global marketplace.

The furniture industry in Norway is an industry dominated by SMEs (Michelsen 2006). Manufacturers are dispersed throughout the country, with a higher concentration in western regions. Several suppliers are located here too, forming an ecosystem of companies at least partially mutually dependent on each other (Michelsen 2006). Fet and Johansen (2001) presented the development of an environmental awareness within the Møre and Romsdal region. This case focuses on how starting from this raised awareness through cleaner production (CP) affected the environmental policy and strategy within the companies and how this resulted in an extensive use and implementation of life cycle assessments (LCA) and development of environmental product declarations (EPDs). This is presented through a collaborative project performed in 4 phases.

14.2 The Furniture Case Project

Phase 1: The Process Focus

Research activities focused on environmental challenges within the furniture industry have a long history. Initially the focus was on cleaner production (CP) in a group of furniture companies with the goal of reducing wastes and emissions through the principles described for CP in Chap. 4 in this book. In parallel, a programme was running with the purpose of identifying appropriate environmental performance indicators (EPIs) for environmental reporting of waste streams and waste treatment within the companies and the municipality where manufacturers were situated (Fet 2000; Fet and Johansen 2001). During these projects, the focus was on companies' environmental performance and the potential for cleaner production processes, consistent with building capacity from Level 1 in the CapSEM Model. As the municipality with the waste treatment plant collaborated closely with companies to find appropriate EPIs for reporting and for following up waste streams, it can be said that Level 4 activities also took place in phase 1. For the purposes of this case, it was possible to continue the transition to sustainability and move from Level 1 to Level 2.

Phase 2: The Life Cycle of the Products

The focus gradually expanded and shifted to assessments of extended supply chains for selected products (Michelsen 2006, 2007a, b; Michelsen et al. 2006). At this time, several LCAs were performed to get an overview of the environmental impacts of the materials used in the products and identify areas for improvements. This was partly carried out with learning in mind; how much detail can be included in environmental performance documentation, what are the environmental hot spots, what are the differences between equivalent products or products with the same functional unit, and, importantly, how can this be communicated.

Since most furniture producers had a large range of product models and variants of the products, an environmental life cycle inventory database for furniture production was created to ease the generation of life cycle assessments of the models (Fet and Skaar 2006; Fet et al. 2006). To ensure the consistency of the performed LCAs and the possibility to compare products, a first version of Product Category Rules (PCR) for furniture was also proposed (Fet et al. 2006). PCR define the criteria for a specific product category and sets out the requirements that must be met when preparing an EPD for products under this category (Fet et al. 2009). The database was used to carry out a large number of LCAs, including those conducted by Michelsen (2007b) where the importance of the different suppliers was assessed.

For companies, it was also important to document indoor emissions of toxic substances that could have a negative effect on human health during the use of the products. This is normally not part of an LCA but was included here to cover other reporting requirements the furniture producers face (Skaar and Jørgensen 2013). The end result of this second phase was a standardised PCR as foundation for EPDs. For companies, it was also important to document indoor emissions of toxic substances that could have a negative effect on human health during the use of the products.

Phase 3: Integration in Environmental Management Systems

A third phase focused on a stepwise framework based on systems engineering principles (Skaar 2013) to be integrated in the environmental management system of the company. The framework consists of six steps, from stakeholder identification, to publishing EPDs and finally auditing the process, see Fig. 14.1. This builds on the same principles as presented in Chap. 12.

A major barrier to scaling up the number of products that could be assessed was the resources needed to develop each EPD, (step 4, Fig. 14.1). The third phase addressed this barrier through the development of the LCA database and EPD software tool. This resulted in a significant reduction in the resources needed to develop an LCA, as a shared database means common background data are only gathered once. It also made it possible to simplify the EPD generation, using a bill of materials (BoM) approach. This meant that instead of an LCA expert developing the EPD, the companies could take responsibility for major parts of the process. With a database and tool in existence, the company could enter a limited number of information to create an EPD: (i) the bill of materials for a product, (ii) specific production data for the product, and (iii) selecting relevant scenarios (e.g., which market it was sold

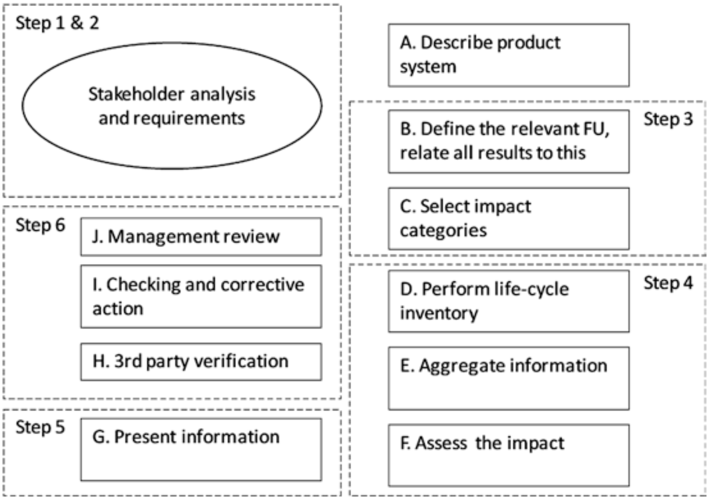

Fig. 14.1 Framework for management and communication of environmental aspects of products. (Skaar 2013)

to). Based on this, an EPD could be developed based on step D to G in Fig. 14.1, and the verification of the EPD could be done by a simplified third-party verification of the database.

The approach developed in phase 3 does not in itself ensure environmental improvement for the products, but it is a basis for integrating life cycle assessment as part of the environmental management system as a tool for improvement. For the life cycle management (LCM) of products, this further supports progression to Level 3 on the CapSEM Model.

Phase 4 – From Environmental Management to Life Cycle Management
The three first phases followed each other in a logical and chronological order; the fourth and last phase ran parallel with the previous phase 2 and 3 and gradually matured. The information gained from environmental analyses of production processes and the life cycle of the products enabled companies to make strategic priorities of improvements targets regarding the most significant aspects.

In Michelsen et al. (2006), different products and potential improvement options were assessed using an eco-efficiency approach, combining information from LCA and life cycle cost assessments. This was done in order to explore the environmental and cost profiles of the models, as well as to start assessing potential improvements for the different models. Figure 14.2 shows the relative eco-efficiency for the models where single scores are used, while Fig. 14.3 shows the relative environmental impact divided in different environmental impact categories.

Figures 14.2 and 14.3 show the total (aggregated) scores for the products, but often it is also necessary for the focal company to know where in the supply chain the impacts occur in order to actually address them. Clift and Wright (2000) identified a tendency that the profit is concentrated towards the end of the production chain, while the environmental impacts are concentrated towards the front part. In other words, those actors who make the most profit are not the same as those having the largest challenges to reduce the environmental impact of the final product. This might be a result of outsourcing challenging processes. However, when the product as such is addressed, this must consider the supply chain as a unit. This clearly highlights the need to move from the first level in the CapSEM model to higher levels; i.e., observed Level 1 improvements can potentially be a product of outsourcing, not product level improvements.

Michelsen et al. (2006) found a similar pattern during their assessments, where the environmental impacts primarily originated from activities at suppliers and/or in the end-of-life phase. One exception was impacts from phytochemicals, originated from the varnishing process which the end-producer addressed in-house (Fig. 14.4).

In order to actually improve the environmental impacts up- and downstream, the focal company must know who the actors are and have the ability to make them change the processes or inputs (Michelsen 2007b). Communication and a common understanding of the goal is thus essential. This could be a significant undertaking job in complex supply chains, but Michelsen (2007b) showed that a limited number of the suppliers were responsible for most of the environmental impact. In fact, a

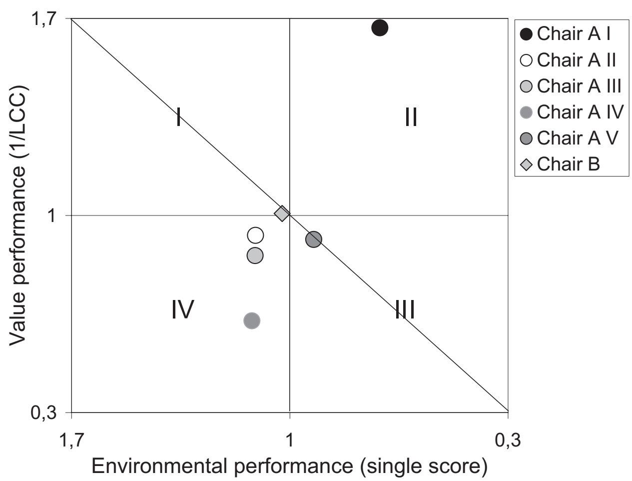

Fig. 14.2 Relative eco-efficiency for 6 different products using an aggregated single score for environmental impact. (Data from Michelsen et al. 2006)

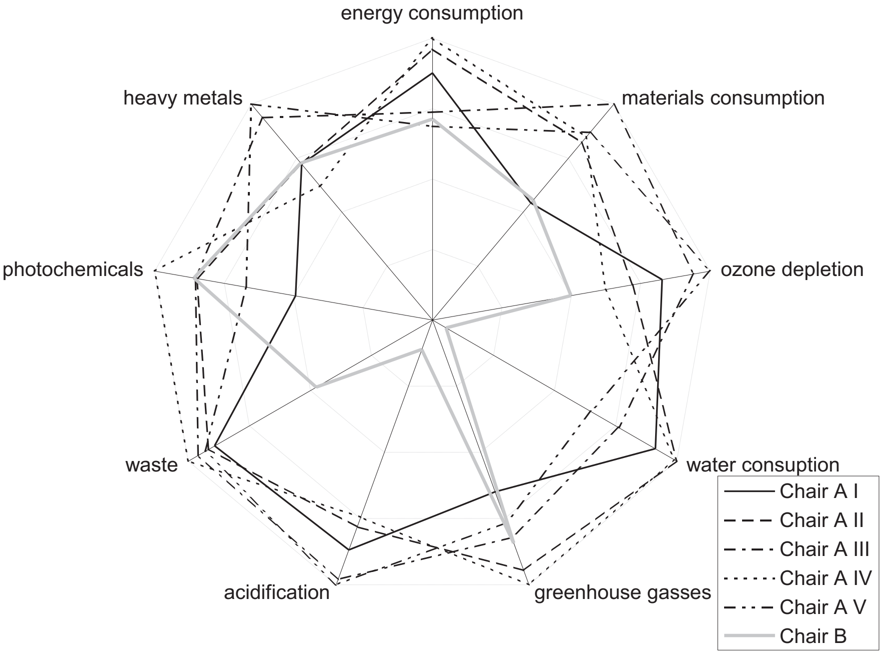

Fig. 14.3 Relative impact on different environmental impact categories for 6 different products. (Data from Michelsen et al. 2006)

chair designed for institutions for elderly care, found the four most important suppliers where responsible for 82.6% of the upstream environmental impact, see Fig. 14.5. One of these was even a subsidiary company and the most important, a producer of polyurethane foam, was a neighbouring company also involved in the local project on improving environmental performance in the region. The fourth phase concluded with recognized possibilities for strategic management of the supply chain in order to improve the performance (Fet and Michelsen 2010) and also move from the first to the third level in the CapSEM Model.

14.2.1 Drivers

There have been three drivers for the successful development of environmental awareness and improvements in the furniture industry resulting from this project.

First, there was already a local initiative for environmental performance in the local community (Fet 2000; Fet and Johansen 2001). The furniture industry is at the cornerstone of the local industry and had a natural role in the initiative from day one.

Second, the long-time relationships between the furniture producers and their (local) suppliers have resulted in strong bonds and the shared perception of a

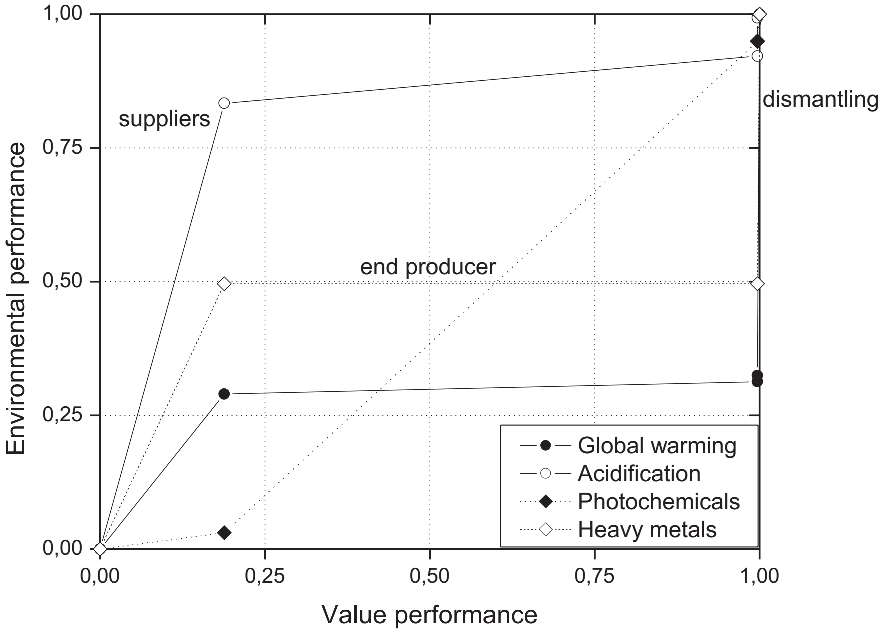

Fig. 14.4 Relative contribution of value performance and environmental performance from suppliers, end producer and dismantling of a chair. (Michelsen et al. 2006)

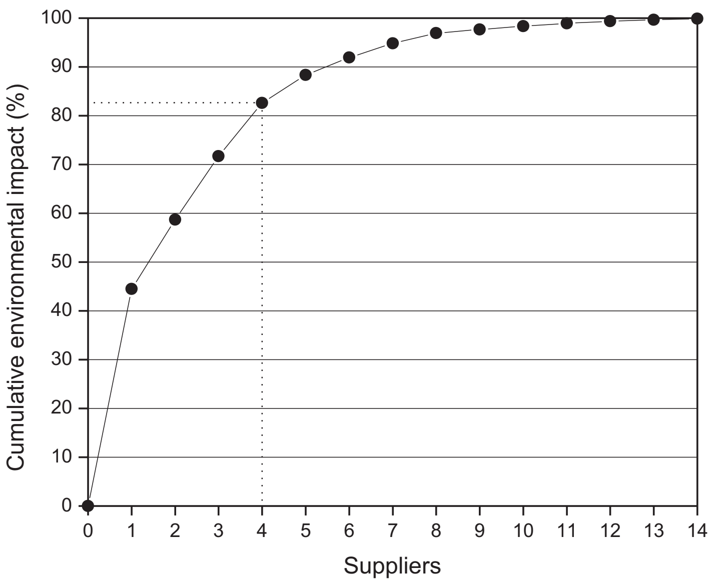

Fig. 14.5 Cumulative environmental impact related to the number of suppliers. (Michelsen 2007b)

common destiny. They were devoted to help each other to perform better as a cluster, not only as single companies. This applied to the furniture producers, who even if they at first glance could be seen as competitors, shared the view that their main competitors are furniture producers in low-cost countries (Michelsen 2006). This fact made the development of a common database for environmental data much easier since the companies involved trusted each other.

The third driver was pressure from outside. The furniture producers are exposed to an increasing demand for environmental information on the products, in particular from public purchasers (Michelsen 2007b; Michelsen and de Boer 2009). They were consequently highly motivated to cooperate with the research activities and provide available data, e.g., the prospects of an improved image for marketing purposes had motivated the manufacturers (Fet 2002, 2004). The streamlined process for EPD-generation for products enabled the furniture producers to provide the requested documentation to public purchasers and then increase marked shares when EPSs were required.

14.3 Concluding Remarks

As addressed in the introduction for this chapter, SMEs often lack competence and resources to systematically work with and improve environmental performance at the process, product and company levels. In this particular case, this need for competence was met through the collaboration through the four phases of research projects with research institutions. The companies thus increased their possibilities to initiate and consolidate their own work on environmental performance. It was also advantageous that the projects continued for more than a decade, as this provided longitudinal feedback to the researchers. The companies during this period were able to establish environmental management systems and were able to integrate the generation of LCAs and EPDs in their everyday activities. As described, the companies have included this in their environmental management systems, approved by top management in the companies. They have succeeded in making this a part of the companies' strategies.

It remains an open question as to whether this could have been accomplished without the long-term collaboration with research institutions. Nevertheless, it stands out as obvious that the collaboration between the companies, both the furniture companies themselves but also their suppliers in the municipality in the region, have been a prerequisite for establishing a common database and thus lowering the bar for performing LCAs. By doing this, companies have collectively been able to expand their environmental focus from process and company-oriented assessments to a product life cycle focus. The generation of and insight in EPDs has given them a competitive advantage.

As also described, the furniture companies have been enabled to identify the suppliers that are most significant for the overall performance of the products. It is still an open question whether they have been able to fully utilize this knowledge in improvements of products, but the presented case study shows that the number of suppliers with significant contributions at least for some products is low and consequently manageable.

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Chapter 15
The Role of Public Sector Buyers: Influencing Systemic Change in the Construction Sector

Shannon Truloff, Luitzen de Boer, Xinlu Qiu, and Annik Magerholm Fet

Abstract Construction machinery is essential to all construction projects and is also a significant contributor to both air pollution and greenhouse gas (GHG) emissions. The Non-Road Mobile Machinery Market (NRMM), otherwise known as the construction machinery market, largely operates using diesel fuel nowadays which has significant negative environmental impacts. It is critical that governmental leaders push suppliers to innovate and implement sustainable solutions in the construction sector. Green Public Procurement (GPP) and Innovation Orientated Public Procurement (IOPP) have emerged as potentially powerful instruments to drive green innovation by providing 'lead markets' for new technologies. City municipalities, regions, nations, and supranational government structures such as the European Union (EU) are starting to use public purchasing to achieve cleaner construction and Zero Emission Construction Sites (ZEMCONs). Early Market Dialogues (EMD) prior to the release of procurement documents can be an effective tool for achieving innovative solutions and for creating positive buyer and supplier collaboration. This case illustrates how the CapSEM Model and toolbox can operate from a top-down approach, initiating collaborative approaches amongst multiple actors, across multiple CapSEM Levels.

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15.1 Introduction

A Zero Emission Construction Site (ZEMCON) is one where construction activities are carried out exclusively with zero-emission construction machinery or equipment, and all transport of goods and people to and from the site use zero emission vehicles (Bellona 2019). There is great potential for reducing greenhouse gas (GHG) emissions, air pollution and noise pollution from construction sites by switching to zero emission alternatives such as electricity, hydrogen, or non-fossil fuels (World Green Building Council (WGBC) 2019). Non-road mobile machinery (NRMM) is defined as "any mobile machine, transportable equipment, or vehicle with or without bodywork or wheels, not intended for the transport of passengers or goods on roads…" (European Regulation (EU) 2016/1628 – NRMM).

15.2 The Construction Sector: Negative Environmental Impacts and Challenges

The global construction sector is responsible for nearly 40% of energy and process related emissions and 23% of the world's GHG emissions across the construction supply chain (Huang et.al. 2018). Furthermore, 5.5% of these GHG emissions are created by the combustion of fossil fuel powering machinery and equipment on construction sites (Huang et.al. 2018). Continuing business as usual in the construction sector which relies on carbon-intensive machinery and materials, threatens to put the world on a fast track towards a global temperature rise of 3 ° C or more (UN Environment Programme 2019). It is therefore, critical for the construction industry to accelerate the speed of decarbonisation to achieve the Paris Agreement and the UN Sustainable Development Goals.

While the European Commission has regulated NRMMs since 1997, GHG emissions have not been included (European Regulation (EU) 2016/1628 – NRMM). Presently, regulations only address carbon monoxide (CO), total hydrocarbons (HC), nitrogen oxides (NOx) and particulate matter (PM), ignoring the impact of CO2 emissions. Regulatory change is needed at the systems level (CapSEM Level 4).

There are also several barriers to achieving a ZEMCON. This includes (but is not limited to), high initial investment costs for fossil-free machinery, adequate electricity infrastructure availability at construction sites, and lack of technical knowledge on both the supply and demand side of the construction market (Bellona 2019). With that said, the opportunity for substantial climate gains by cities when switching to fossil-free and zero emission technologies far outweighs the costs.

15.2.1 Opportunities: Functional Buyer-Supplier Ecosystem for Green Public Procurement

The European Commission (2008:4) defines GPP activity as: "A process in which public entities want to procure goods, services, and labor with a reduced environmental footprint throughout the life cycle compared to those goods, services, and labor with the same primary function as they would otherwise purchase". Typically, GPP will include environmental requirements and criteria, and this is what differentiates it from traditional procurement (Cheng et al. 2018; European Commission 2016; Igarashi et al. 2015; Varnäs et al. 2009). When utilising GPP, public actors can improve their environmental performance in low−/ zero-emission solutions for construction sites, while encouraging their suppliers to also improve (Varnäs et al. 2009).

Municipalities own a significant proportion of infrastructure and building projects and can leveraging their public sector purchasing power using GPP. An innovative public procurement process will necessitate a higher degree of collaboration between suppliers and customers than traditional procurement (Edquist and Zabala-Iturriagagoitia 2012). Transitioning from traditional construction machinery to fossil-free or zero-emission solutions requires a collaborative approach amongst actors across CapSEM Levels. Establishing a functional buyer-supplier Ecosystem for Zero Emission Construction Sites (EZEMCON) can help the mobilization of the market towards delivering a ZEMCON. Such an ecosystem includes actors at every CapSEM Level.

- Level 4: the public buyers and governmental leaders
- Level 3: the construction companies and developers
- Level 2: subcontractors and equipment suppliers
- Level 1: the construction site itself

15.2.2 Framework for Innovation Oriented Public Procurement (IOPP)

As indicated already, public procurement is "a powerful tool for spending public money in an efficient, sustainable and strategic manner" (European Commission 2017). It is seen as a strategic policy instrument to (1) enable investment in the real economy, (2) stimulate demand to increase competitiveness based on innovation and digitalization, (3) support the transition to a resource-efficient, energy-efficient and circular economy, and (4) foster sustainable economic development and more equal, inclusive societies (European Commission 2017).

As Lember et al. (2014) highlight, innovation and public procurement may be related to each other in different ways. Public procurement can be understood as a tool to stimulate innovation by targeting a new product or service, or it also refers to activities that aims to induce innovation possibilities by creating innovation-conducive environments to stimulate learning, e.g., pre-commercial procurement (Lember et al. 2014). In this case, we adopt the definition of Innovation Orientated Public Procurement (IOPP) by Lember et al. (2014) that includes both above-mentioned approaches, which emphasize that the public sector uses its purchasing power to act as an early adopter of innovative solutions that do not exist in the market or are not yet available on a large scale commercial basis.

15.2.3 Innovation-Oriented Public Procurement: Framework and Dialogue

There are four different policy modes in which innovation-oriented public procurement (IOPP) can be applied; each IOPP mode has distinct goals and means, institutional and policy-capacity requirements and, consequently, distinctive challenges (Lember et al. 2014).

The most influential mode of IOPP *is to use it as a technology procurement policy.* By applying its monopolistic power, public procurement can guide the technology development and innovation by indirect mild policy intervention or frequent strong intervention to create and diffuse new technology. The development of new technological solutions can also have innovation and economic spill-over effects to other industries. IOPP can also be used *as R & D policy* when it targets radical innovation with high-level R & D work to meet specific public demand. In EU, this is mostly implemented with pre-commercial public procurement. Utilising IOPP *as a generic innovation policy* has been gaining a lot of attention since 2000s. It focuses on creating an innovation-friendly public procurement culture to support innovation. Many procurement practices and tools have been developed and adopted, such as applying performance/environmental specifications, competitive dialogue, and market dialogue. The last mode of IOPP is to apply it as *"no policy" policy.* This mode is often chosen unconsciously because the public authorities are not aware of the alternatives. It can also be chosen because some governments assume the public funds should be spent in the safest way, and that innovation is linked with high risk.

Table 16.1 illustrates how different IOPP models can be adopted in the CapSEM Model to facilitate Ecosystem for Zero Emission Construction Sites (EZEMCONs). At CapSEM Level 4, IOPP can be used by cross-national networks, national, and cities by adopting a technology procurement policy to drive technological innovation. IOPP can also operate as a generic innovation policy that uses dialogue to align expectations and strengthen mutual insights between the public buyers and suppliers, at CapSEM Levels 3 and 4, respectively. At CapSEM level 3, IOPP can be applied generically to align emission targets (national or city level) and procurement specifications for a specific construction project.

15.2.4 *Early Market Dialogue for Innovation-Oriented Public Procurement*

Early Market Dialogue (EMD) is a tool for achieving innovative procurement as described above, and it refers to the range of activities through which a procuring entity or public buyer at CapSEM Level 4 engages with potential suppliers at Level 3, before procurement documents are released. The national program for Innovative procurement in Norway (Innovative anskaffelser 2020), identifies that EMD is an important way of enhancing market's knowledge and it should be mutually beneficial. Public buyers can use dialogue prior to procurement to increase predictability for the construction machinery market. This can give market actors the confidence to invest in more sustainable products and construction methods, to bring solutions to scale. Dialogue process can stimulate market interest among, and competition between potential suppliers which will improve the outcomes of a subsequent competitive procurement process (Watt 2018). In Table 15.1, typical dialogue participants engaging in innovation-oriented public procurement (IOPP) for a ZEMCON have been identified.

15.3 Implementation at Global, Regional, National, and City Levels

This section illustrates key projects at the global, regional, national, and city level respectively which aim to create an Ecosystem for Zero Emission Construction Sites (EZEMCONs) for cleaner construction practices.

15.3.1 *Global Action and Joint Initiatives by Cities: Members of ICLEI and C40*

C40 Cities Climate Leadership Group is a network of mayors of nearly 100 world-leading cities collaborating to deliver the urgent action needed to confront the climate crisis. ICLEI Local Governments for Sustainability is a global network of more than 2500 local and regional governments committed to sustainable urban development. These two organizations work very closely for the development of ZEMCONs and adaptation of NRMM to fossil free. In October 2019, at the C40 Mayors' Summit in Copenhagen, a common political declaration known as the 'C40's Clean Construction Declaration', was made. There were three targets, including the reduction of embodied emissions from new builds, from infrastructure, and procuring using zero emission construction machinery from 2025. Specifically, the declaration demands zero emission construction machinery by the signature cities (Budapest, Los Angeles, Mexico City, Oslo, San Francisco) projects from 2025, and zero emission construction sites city-wide by 2030, where available.

Table 15.1 Application of IOPP modes for ZEMCON in the CapSEM Model

CapSEM level	IOPP level	Dominant IOPP policy approach (Lember et al. 2014)	Typical dialogue participants	Example project actors in IOPP for ZEMCONs
Level 4	Cross-national, network of large cities	**IOPP as technology policy** – Driving the development of electrical NRMM	Large, global NRMM manufacturers, facilitating third parties (EU), network of large buyers (cities)	C40 mayors' commitment to actions for clean construction; ICLEI and EUROCITIES, big buyers initiative (BBI), Scandinavian green public procurement Alliance (SGPPA) on NRMMs
	National driven by large cities	**IOPP as generic innovation policy, technology policy or R & D policy**– Using dialogue to align expectations and strengthen mutual insights	Large city, additional (smaller) cities, national third party, construction firms, other regional ecosystem members	Finnish green deal with a commitment on emission free construction sites
	City level	**IOPP as generic innovation policy** – Aligning local ecosystem members, both internally and externally for a range of projects or more in general	Individual city, internal stakeholders, local construction firms, national third party, regional ecosystem members, e.g. electricity providers	Oslo, Copenhagen, Helsinki, Trondheim, Budapest and Amsterdam, among others.
Level 3	Project level	**IOPP as generic policy** – Aligning emission targets and procurement specifications for a specific construction project	Individual city, primarily procurement and EM advisors, local supply network (construction firms, subcontractors)	Omsorgsbygg, Volvo, Caterpillar, and Hitachi construction machinery, among others.

This is an example of a top-down approach from governmental leaders at CapSEM Level 4 which in turn places pressure on lower levels.

15.3.2 Regional Action: Scandinavian Green Public Procurement Alliance (SGPPA) and Big Buyers Initiative (BBI)

The Scandinavian Green Public Procurement Alliance project (SGPPA 2020) operating between 2016 and 2019 is an example of cross border joint procurement partnership between the City of Copenhagen, Oslo, and Stockholm, and was funded by the Carbon Neutral Cities Alliance. A key outcome of the alliance was the establishment of a Dynamic Purchasing System (DPS) which facilitated the possibility for the cities of Oslo and Copenhagen to purchase machines in the future that are not available currently.[1] DPS is an innovative procuring procedure that typically spans several years and operates in this case to signal to the businesses on Level 3 of the CapSEM Model, the growing demand for emission free machines. The City of Oslo and Copenhagen continue to collaborate and operate the cross-border DPS of NRMMs via a web-based platform managed by Mercell.

The Big Buyers Initiative (BBI) is a European Commission programme for encouraging collaboration between big public buyers (cities at CapSEM Level 4) and the construction market (at CapSEM Level 3). The initial project was conducted between 2018 and 2020, with a second phase between 2021 and 2022 based on its success. One of the three established working groups focuses on ZEMCONs with city members from Europe, including Amsterdam, Brussels, Budapest, Copenhagen, Helsinki, Lisbon, Oslo, Trondheim, and Vienna. The multi-city collaboration brought about innovative partnerships and increased political will to transition to cleaner construction machinery though using EMD. Such regional projects allow engaged cities to test procurement procedures such as DPS and environmental award criteria in a coordinated and targeted manner across public construction projects, with mutual learnings.

15.3.3 National Action: Finland Targeting Emissions in the Construction Sector

In Finland, the national government is placing top-down pressure on its cities through legislation drafted which obligates local governments to draw up climate plans for low-carbon procurement in a bid to move closer to fossil free construction sites (HNRY project 2020). The Finnish government has anchored this top-down initiative to the EU Green Deal agreement for sustainable procurement (2022).

15.3.4 City Action: Oslo Leads Climate Action for Clean Construction Sites

The city of Oslo took a lead role in setting ambitious demands on potential suppliers and infrastructure providers well before large electric construction machines were commercially available (DNV GL 2019). Fossil-free (biofuels) construction sites have been the minimum requirement for public projects by Oslo municipality since

[1] Due to legal and administrative differences between the countries it was not possible for the City of Stockholm to join the final procurement process.

2017 (DNV GL Rapport 2018). The city has now set requirements that all suppliers must use emission-free construction machinery by 2025 (Klimakur 2030, 2020/2022). To achieve this, the municipality utilises allocation criteria that rewards suppliers who can deliver emission-free and biogas-powered solutions. Additionally, the municipality requires that all vehicles used for the transport of masses and waste must be fossil-free and that heating and drying of the construction site must be emission-free. The City of Oslo was the first in the world to launch a zero-emission construction site, using all electric machinery to complete street renovation works at Olav Vs Gate (Moore 2020). The application of IOPP and EMD for innovative GPP and applying significant weight on environmental award criterion for construction contract has underpinned success.

15.4 Discussion

Historically the CapSEM Model works according to a bottom-up approach (Fet and Knudson 2021), starting with improvements in production activities and their environmental impacts at Level 1, the production processes, and at Level 2, the products, and their value chains. Transition to higher levels then happens with implementation and improvements in management systems and sustainability monitoring at the organizational Level 3, and at the larger systems Level 4 with a diversity of actors. The CapSEM Model focuses on environmental aspects, and in the case of ZEMCONs, at the highest level, social aspects are incorporated, such as the well-being of construction workers and communities.

For the case presented here, rather than applying lower level CapSEM tools to facilitate moving to higher levels, we are demonstrating a top-down approach using tools available at higher levels such as policy programmes and regulations to bring about systemic change.

15.4.1 Top-Down Systemic Change and the CapSEM Toolbox

To achieve a ZEMCON, decision makers, such as construction firms and machinery producers focus influence on Level 2 and 1 to implement Cleaner Production (CP). Starting at the highest CapSEM Level 4, government leaders and public buyers can implement systems-related changes by applying principles of systems engineering (SE) as a ‘process’ (see Chap. 12). In the construction machinery market, it is important to facilitate the integration of different actors’ views, environmental perspectives, business strategies and organization management for improved environmental performance. SE operates by establishing a functional ecosystem for the ZEMCON. Within this EZEMCON, frameworks such as IOPP, and practical tools such as early market dialogue (EMD) and GPP help align expectations and strengthen common knowledge across Level 3 and 4 of the CapSEM Model. This in turn sets the foundation for sustainable development in a long-term perspective.

Policy programmes for cleaner construction sites and regulations help to set goals for the larger societal system at the city or national level for example. Environmentally weighted criteria in GPP (created at level 4 and together in dialogue with Level 3) can be used to implement changes for more sustainable supply chain management (SCM) down-stream in the construction value chain (Level 2) as well as design for environment (DFE). Leaders and public buyers can instruct their pre-tender customers on Level 3 (such as Volvo or site a developer) to establish, transparent reporting, organizational routines such as implementing environmental management systems (EMS) (ISO 2015) and doing environmental performance evaluations (EPE) (ISO 2021). Adoption at organisational Level (3) of key performance indicators (KPIs) or certification schemes will help govern the construction market production processes and product value chains for NRMMs at the lower levels. Furthermore, at Level 3 the construction firm can influence its' subcontractors and equipment suppliers (Level 2) down the value chain, by requiring that the supplier produce environmental product declarations (EPDs) for the development of NRMMs and its component products. Pressure from the upper levels forces cleaner production (CP) at the construction site itself (Level 1).

15.4.2 Linkages to Lower CapSEM Levels and Tools

A valuable information feedback loop takes place when community leaders at higher CapSEM Levels learn from, and amend, policy and strategies according to knowledge gained about environmental performance at lower CapSEM Levels. Knowledge about individual construction sites' GHG emissions is gained by using input/output (I/O) tools and cleaner production (CP) practice which monitor the environmental impacts during production and manufacturing processes at Level 1. Information gained by using tools such as Life Cycle Analysis (LCA) at Level 2 for a NRMM and its component parts helps organisations such as Hitachi Construction Machinery (at Level 3) and the municipality buyer (at Level 4) make informed decisions. Ultimately the community at Level 4 is held accountable through use of analytical models for measuring the material flows (MFA) on construction sites.

15.5 Concluding Remarks

When public buyers, cities and nations, follow the top-down CapSEM Model approach, they adopt the role of *change maker* in a larger system. Zero-emission solutions are already available on the European market for smaller NRMMs, however greater demand is needed to accelerate innovation, especially for larger heavy machines.

This case illustrates how the CapSEM Model supports a collaborative approach across actors within multiple CapSEM Levels. At community level (Level 4), strong political support and dedicated financing for ZEMCON pilots is required. Early market dialogue (EMD) across Levels 3 and 4 can help knowledge transfer mechanisms and capacity building for ZEMCONS. Leveraging the strategic purchasing power of public authorities and other top-down demand initiatives such as EU-level regulation on carbon emissions from construction machinery can accelerate market innovation and extend uptake of emission-free NRMM solutions. Multi-actor dialogues together with a commitment from both public and private actors to decarbonisation is essential.

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Chapter 16
CapSEM Applied to the Construction Sector

Magnus Sparrevik, Luitzen de Boer, Ottar Michelsen, and Christofer Skaar

Abstract The construction sector and built environment have the potential to impact on a variety of systemic dimensions, ranging from specific processes in the production of construction materials to pan-national regulations affecting regional areas and cities. This case study uses the CapSEM Model in order to identify the potential enabling and constraining impact of different methods, schemes and regulations for reducing environmental impact in the construction sector. The use of a systemic perspective highlights that all methodologies are working recursively in actor-networks, thereby affecting society and the market differently, depending on the systemic level.

16.1 Introduction

The construction industry and built environment represent significant pressure on the environment by being the largest consumer of natural resources in the world: it alone uses over a third of the energy produced annually worldwide (Munaro et al. 2020). In addition, the rate of urbanisation has an increasingly negative impact on biodiversity around the globe (McDonald et al. 2008). The need to reduce this impact by moving away from a linear consumption pattern into more circular solutions, thus reducing the footprint of the built environment is therefore evident (Arora et al. 2020).

There are several ways the construction sector may reduce the impacts from the activity involving material considerations, design and resource use, see Fig. 16.1.

To effectively reduce environmental impact during the construction, use and end-of life phase of a building, there is a need for environmental assessment tools with the ability to analyse environmental aspects and impacts during the lifetime of the

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Fig. 16.1 Focus areas to reduce environmental impacts in the construction sector. (Sparrevik et al. (2021)

building solution, thus capturing that 'contribution' across different impact categories simultaneously. In addition, life cycle-based management schemes, and regulations support environmental performance across the building life cycle better, consequently affecting the variety of actors in the construction industry. The individual effects of these methods, schemes and regulations are widely investigated in literature (Gallego-Schmid et al. 2020; Górecki et al. 2019; Munaro et al. 2020). However, it is also important to consider the role and impact of these methods in different systemic dimensions, a topic often overlooked. Applying the CapSEM Model to the construction industry and built environment gives a better understanding of impacts horizontally (across topics and involved sectors), and vertically (from individual projects to international bodies).

16.2 Implementation

According to the CapSEM Model, methodologies for systematic implementation of sustainable solutions can be organised in a stepwise progression through four levels: (1) process, (2) product, (3) organisation, and (4) system. The methods may be separated across two dimensions: (i) in terms of the increasing complexity of the scope (increasing systemic scope in the original model) and (ii) by the increasing comprehensiveness of performance (increasing performance scope in the original model). How one defines the content of each level depends on the point of entry, i.e., from which perspective one views the systemic levels. Figure 16.2 shows how the model can be adapted to the construction sector with the most important assessment methods indicated at each level, (Sparrevik et al. 2021). The point of entry here is the building, seen itself as a product and placed in an organisational context.

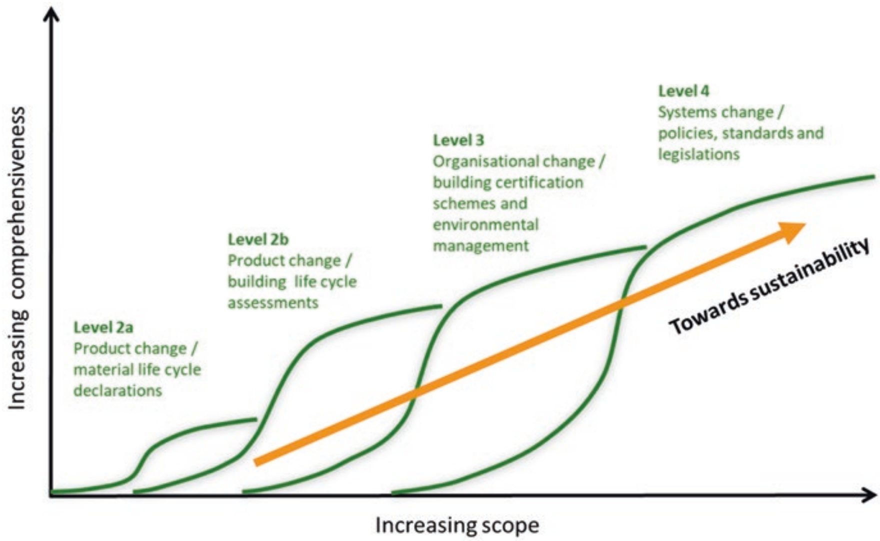

Fig. 16.2 Adapting the CAPSEM Model to the construction sector. (Sparrevik et al. 2021)

Each subsequent level is then defined according to this approach. We can disregard the process level and assume that process improvements and related impact assessment methods are an integral part of the work by suppliers to improve their products.

The initial product level connects to resource performance of the components of the building and the performance of the building itself. We may therefore divide this level into two sub-levels: (i) building components and (ii) the building itself.

For building components (i), using materials with a high degree of recycled content, and produced without polluting materials, ensures environmental benefits. High technical capacity and long lifetime expectancy are also important to keep the products and materials in use for as long as possible, thus reducing the environmental footprint in the life cycle. In this case, it is not only the embodied emissions from products and materials that count, but also the operational emissions and end-of-life treatment. For the building (ii), the location of the building affects travel patterns for residents and users of the building, causing emissions from transporting people, goods and services to the building. Since the lifetime of a building is long, minimising the environmental footprint from the building perspective may require further optimisation between construction (including maintenance and renovation) and operational emissions.

According to the model in Fig. 16.2, the organisation level relates to standardisation across construction projects in a geographical or organisational context. Examples are strategic decisions taken to follow certain standards or certification arrangements that ensure buildings are constructed according to organisational objectives. This may create new internal markets based on standardised construction activities, or result in new solutions, thus affecting the whole supply chain. However, this level also refers to the strategic decisions made by entrepreneurs in the early design phase of new buildings, new construction projects and to the development of new environmentally friendly concepts.

Finally, the system level relates to larger initiatives, either cascading from pan-national regulations, such as EU regulations, national regulations, standards or from various voluntary initiatives at the national or regional level, such as the development of the European framework for sustainable systems (EU 2020). Environmental friendliness in the systemic dimension has a broader impact than at other levels. It allows for long time predictability, thus creating a new market that may compete financially with established traditional solutions.

Sparrevik et al. (2021) highlights several findings with management implications for advancing environmental performance in the construction industry, thus relating the complexity and scope of the decision to the CAPSEM Model of systemic thinking. As summarised in Table 16.1, the methodologies, which are all based on life cycle thinking and aimed to reduce environmental impact, will have different functions depending on their placement in the CAPSEM Model. In practice, effects are thus tailored to the appropriate systemic level where they can act as both enablers and constraints for improvement, depending on the context.

For standardised product (building component) impact assessments, use of environmental product declarations (EPD) to provide transparent information on the environmental impact have gained popularity worldwide and EPDs are now widely available for most products and materials in the construction sector (Andersen et al. 2019; Burke et al. 2018; Passer et al. 2015). The use of EPDs is transparent and allows the procurer access to information about the environmental impact of a material, a product or service, in order to be able to make well-informed decisions. By using EPDs, decisions can be made by the builder to choose to select materials and products with the lowest environmental impacts. Suppliers will thus be encouraged to use more recycled materials to reduce environmental impact, but also to improve production processes through cleaner production technologies, lower energy use and selection of more sustainable transportation services. However, not all life cycle

Table 16.1 Overview of the potential enabling and constraining impact of different methods, schemes and regulations for reducing environmental impact in the construction sector

Level	Methodology	Potential enabling implication	Potential constraining implication
2a	Material life cycle declarations (EPD)	Better performance at supplier level, product improvements	The ability to compare impacts across areas and life cycle stages
2b	Building life cycle assessments (LCA)	Optimal building design and circular solutions	Standardisation due to case-to-case based solutions
3	Building certification schemes, environmental management	Higher built environment standard and better organisational performance	Unidirectional effect due to voluntariness and user-driven ambition levels
4	Policies, standards and legislations	Broad scale systemic effects	Voluntary initiatives for innovative solutions

Modified from Sparrevik et al. (2021)

stages are treated equally (Durão et al. 2020) and this may bias the results towards materials and products with low emissions in the production stage without giving enough focus on impacts created in the use or end of life stages of the products.

Use of life cycle assessments (LCA) for buildings is far more comprehensive than of each material. On the other hand, using an LCA is more likely to result in an optimal building design and circular solutions adapted to the wider context. For example re-use of building materials will according to Arora et al. (2020) and Eberhardt et al. (2019) reduce environmental life cycle impacts from the building perspective, but extensive refurbishment to enhance energy performance may be counterproductive due to the technical lifetime of building materials, especially if renewable energy is used in the building. The optimum balance here is difficult to evaluate on the material level, but may more easily be optimized at the building level. However, since circular solutions on the building level are mainly developed on a case by case basis, standardised solutions might be more costly and difficult to reproduce since improvements should ideally be tailored to each individual building.

On an organisational level, building certification schemes and environmental management systems (EMS) are widely used both to achieve higher built environment standard as well as better organisational performance. In building certification schemes (LEED,[1] BREEAM[2] or similar), the proposed project is scored against specific predefined targets covering a variety of topics valid for the construction and use phases of the building. Introduction of EMS will also require the organisation to identify significant environmental aspects such as energy, material use and water efficiency and set objectives and targets accordingly. Even though building certification and certified EMS affords the possibility of benchmarking environmental status at the organisational level (Cole and Valdebenito 2013), these systems are still voluntary and allow for the user to set appropriate ambitions in terms of performance. In addition, the various schemes emphasise sustainability aspects differently, and the content and weighing are neither unified, nor coordinated in their development (Mattoni et al. 2018).

Finally, at the system level, a wide variety of policy, standards, and regulations with expected broad scale systemic effects exist. Various EU policies on resource policy direct the construction sector towards circularity and are enforced by national regulations, standards and priorities to be effective (Domenech and Bahn-Walkowiak 2019). Requirements related to energy management, nature conservation and technical design to avoid pollution are examples of requirements often found in regulatory frameworks. More innovative activities depending on cooperation between market and builders, such as the introduction of emission free construction sites, are difficult to regulate unless demonstrated as successful at a lower building level (Fufa et al. 2018). On the contrary, detailed non-functional requirements for performance may, in fact, be counterproductive for innovation (Sparrevik et al. 2018).

[1] LEED (Leadership in Energy and Environmental Design).

[2] BREEAM (Building Research Establishment Environmental Assessment Method).

16.3 Concluding Remarks

This example of applying the CapSEM model to the construction sector and built environment shows the benefit of reviewing the methodology using a systemic perspective, especially for policy implications. Two findings illustrate this.

The first finding emphasises the importance of addressing environmental performance with the correct complexity context to be able to make well balanced and sustainable decisions (Labonnote et al. 2017). For example, embodied material related emissions often dominate GHG emissions in a building life cycle (Wiik et al. 2018), thus, suggesting a strong focus on process improvements at the supplier level. This is inherently robust and positive since it pushes the market to be innovative and develop more environmentally friendly solutions. However, from a broader perspective and higher systemic perspective, decarbonisation of the energy supply may be a more effective enabler for reduced environmental impact than material focus depending on the energy situation in each country and expected life cycle cost savings (Ibn-Mohammed 2017). A recursive structure will then encompass both materials and energy but allows for different prioritisations depending on the context of the decision.

The second finding stresses the importance of finding the appropriate scope for environmental improvements. As Pomponi and Moncaster (2017) point to, circular building design encompasses not only environmental and technical aspects but also governmental and behavioural dimensions. These are best developed through organisational tools such as building certification schemes or even by regulatory work at the system level. However, high score levels in schemes and more stringent regulations are not possible without proper technical solutions at the product level or at a functioning market with the ability to supply solutions.

With a systemic perspective, it becomes clearer that all methods, schemes and regulation are working recursively in the actor-networks and therefore affects society and the market differently depending on the systemic level. Methods at lower systemic levels, such as the use of EPDs and LCA of buildings, may stimulate the market to create environmentally friendly solutions. However, methods in higher systemic levels, such as building certification, environmental management systems and regulations, are used by real estate builders, trade organisations and governments to create incentives for development and innovation.

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Chapter 17
Application of Material Flow Analysis: Mapping Plastics Within the Fishing Sector in Norway

Paritosh C. Deshpande and Arron W. Tippett

Abstract Plastic in our marine environment is now ubiquitous. Abandoned lost or otherwise discarded fishing gear (ALDFG) is of particular concern due to its ability to continue to function as a trap for marine organisms. In order for decision makers to act on this grave issue, we require data on the flow of ALDFG into the marine environment. One key tool for revealing the flow of material within a specific system is Material Flow Analysis (MFA). MFA takes a life cycle approach (cradle to grave) to assess energy or material flows in a system within space and time boundaries. It can be applied at multiple levels from the industrial process level to the national level. This chapter presents a case study of an MFA conducted on fishing gear in Norway. The MFA methodology was used in this case study to assess the flow of plastic fishing gear from production through to recycling, final disposal or loss to the marine environment. Data was collected for the MFA through stakeholder interviews, literature reviews and analysis of government data sets. The MFA revealed that around 4000 tons of plastic fishing gear enters the system in Norway and around 400 tons enter the marine environment each year. An analysis of the implications of the MFA for the key actors within the life cycle chain of fishing gear is presented and a short description of the links between MFA and the circular economy and sustainable development is provided. Furthermore, the relevance and implications of using MFA tool for policy making at national and regional level is discussed and elaborated while associated challenges are presented here.

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17.1 Introduction

Marine plastic pollution is now seen as a threat to the safe operating space for humanity, due to its persistence within the marine environment and its ubiquity (Villarrubia-Gómez et al. 2018), being found in all environments from coastal soil substrates (Cyvin et al. 2021) to the digestive systems of marine species (Gall and Thompson 2015). 8300 million metric tonnes of plastic have been produced since the 1950s, with only 9% being recycled and the majority either lost to the natural environment or landfilled (Geyer et al. 2017). The first recording of plastic in the marine environment was made in 1957 with recordings growing substantially since the 1990s. (Ostle et al. 2019). Jambeck et al. (2015) have estimated that between 4.8 and 12.7 million tonnes of plastic entered the marine environment in 2010 and predict that between 10.4 and 27.7 million tonnes of plastic will enter the marine environment in 2025, if no strategies are implemented to reduce the mismanagement of plastic waste streams on land. A more recent study by Borrelle et al. (2020) predicts that annual emissions of plastic waste to aquatic systems (freshwater and marine) could reach 53 million tonnes by 2030, even when considering current government commitments made to improve the waste management system.

One significant omission from the studies by Jambeck et al. (2015) and Borrelle et al. (2020) was plastic entering the marine environment directly from marine industries, such as *abandoned, lost, or otherwise discarded fishing gear* (ALDFG). ALDFG is a major concern for the marine environment due to its design properties. Fishing gear (FG) is designed to capture or kill and to persist in the natural environment and it continues to meet these design requirements when lost in our seas and oceans (Deshpande and Aspen 2018). Therefore, calculating the volume of ALDFGs entering the marine environment is critical to help policy and decision makers design practical solutions to solve the issue.

In resource management terminology, *information* refers to the fundamental knowledge about stocks, flows, and processes within the resource system as well as about the human-environment interactions affecting the system (Ostrom 2009). Highly aggregated information may ignore or average out local data essential to identifying future problems and developing sustainable solutions. FGs are resources in the fishing sector, and literature suggests the overall unavailability of data and monitoring methods to provide sound scientific information on the amount of plastics in ALDFG that enter the ocean and is available after end-of-life (EOL) collections (Deshpande 2020).

At present, plastics generally follow a linear economy model, where products have a single lifecycle: virgin material is used to produce products that are then sent for disposal in landfills or directly into the natural environment for most of these products. The circular economy (CE) approach presents an alternative model where materials are given several lifecycles, through the 9Rs framework, for example: reuse, reparation, recycling and more. The CE model is hailed by the EU and other international bodies as a solution to the issue of plastic pollution (EC 2018). One of the key tools for generating evidence for the CE strategies is Material Flow Analysis

(MFA). (Brunner and Rechberger 2016) define MFA as "a systematic assessment of the flows and stocks of materials within a system defined in space and time". MFA can be used to reveal the stocks and flows of valuable resources within a system to help industry and businesses, such as plastic recyclers, understand the potential for developing an economically valuable solution.

To build robust resource management strategies and realize sustainable CE opportunities that are capable of utilizing untapped resources across regions, it is essential to know the amount of plastic available for recycling from the fishing sector (Deshpande and Aspen 2018). The following case study presents the application of MFA tool to estimate the flows of plastic polymers from fishing process or activity as presented in Level 1 of the CAPSEM Model.

17.2 Mapping Plastics from Processes Within Fishing Sector

The basic principle of MFA is the conservation of matter and energy in isolated systems, delimited by boundaries of time and space and following the mass-balance principle (Brunner and Rechberger 2016). As explained in the CapSEM Model, MFA is a valuable tool for assessing material and energy flows from the processes and/or industrial sector. Typically, MFA of a selected substance includes the main life cycle stages namely, mine, production, manufacturing, use, maintenance and disposal. The in-depth methodology of MFA is presented in Part II Chap. 5. This case study presents, and elaborates upon, the successful application of MFA method in mapping life cycle processes from the fishing sector and thereby measure the loads of plastic from fishing practices in Norway.

In applying MFA, (Deshpande et al. 2020) studied six major commercial FG types, namely trawls, purse seines, Danish seines, gillnets, longlines, traps/pots and their associated ropes, deployed by the Norwegian commercial fishing fleet. The data was further collected from gear producers, suppliers, fishers (Deshpande et al. 2019), collectors, authorities, and waste management facilities within the region to model the flows of plastics polymers, polypropylene, polyethylene, and Nylon, which are used as the building blocks of advanced gears (Brown and Macfadyen 2007). Data was primarily collected using published literature, government statistics, and interviews of stakeholders. Table 17.1 presents the stakeholder involved and the type of information obtained from each stakeholder category during the period of 2018–2019.

The study focuses solely on the system of the Norwegian commercial fishing fleet, through both use and post-use processes. The recreational fishing and foreign fishing vessels operating in Norway are neglected. FGs are defined using an expansive definition proposed by FAO. According to FAO, FG are defined as "any physical device or part thereof or combination of items that may be placed on or in the water or on the seabed with the intended purpose of capturing or controlling for subsequent capture or harvesting, marine or freshwater organisms whether or not it is used in association with a vessel" (FAO 2016). Throughout the text, the term *plastics* includes polyethylene (PE), polypropylene (PP) and Nylon (PA). Although the FG unit contains other materials such as metals, lead, polyvinyl chloride (PVC) and wires, plastics constitute around 60–90% of any gear type. Therefore, plastic polymers from FG are treated as resources in developing management strategies throughout this study. A static MFA model was built to present the 2016 stocks and

Table 17.1 Summary of relevant information obtained from MFA on each stakeholder across the life cycle of fishing gear and its potential application

Stakeholder category	Data obtained *for* MFA model from stakeholders	Information provided to stakeholders from MFA study	Application
Gear producers	Annual quantities of FGs sold and material components of each FG type	Amount of FG sold of each type, The market/demand for each type of FGs, The typical tendencies of repair and reuse Need for material improvement for ease in recycling	Development of new FG design suitable for recycling Assessing need for building repair facilities for fishers
Fishers (resource users)	Typical life span of FGs, repair and disposal patterns, purchase patterns and typical rate of FG loss in the ocean upon deployment	The typical life span of FG types The FGs types more vulnerable to get lost in the ocean upon deployment The typical repair patterns of various FG types	Developing best practice guide for handling and management of FG types
Beach clean-up programme	Typical amount of FGs plastic collected through beach clean-up surveys	Efficiency of clean-up operations Need for effective and efficient data management plan	Best practice guide for effective classification and reporting of collected waste items
Regulatory actors	Typical amount of FGs plastic collected through ocean clean-up surveys	Efficiency of clean-up operations Data on potential hotspots for leakage of plastics in the environment Information for effective policy making	Suitable regulatory response for management of plastics from fishing sector
Waste management companies	Typical volume of waste FGs handled annual by WMCs, typical fate of waste FGs (sent to recycle, incineration or landfilling)	The typical handling patterns of waste FGs The amounts of waste FGs generated every year	Best practice guide for waste managers for effective segregation of waste FGs to improve recycling

(continued)

Table 17.1 (continued)

Stakeholder category	Data obtained *for* MFA model from stakeholders	Information provided to stakeholders from MFA study	Application
Recyclers	Typical challenges in FG recycling	The amounts of waste FGs generated every year The typical rate of recycling of FGs Challenges in FG recycling The amounts of recycled polymers produced every year	Considering business case of recycling Improvement in infrastructure for recycling within the region

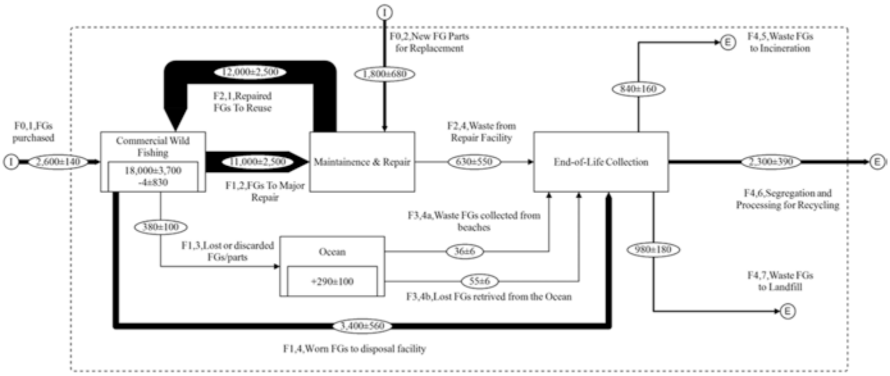

Fig. 17.1 MFA of plastic (PP, PE, and Nylon) from six fishing gears used by the commercial fishing fleet of Norway in 2016 (tons/year). (Adapted from Deshpande et al. 2020)

flows of plastics from FGs because of the maximum data availability obtained through data collection rounds. Primary modelling and flow calculations were performed in Microsoft Excel, while STAN v2.6.8 was used for further data reconciliation (Vienna University of Technology, Vienna, Austria).

Figure 17.1 presents the typical MFA model depicting the annual flow of plastics from the fishing sector of Norway (Deshpande et al. 2020). The results summarize that around 4000 tons of plastics enter the system as new FGs or FG parts every year in Norway. The fishing activity results in leakage of 400 tons of FGs as ALDFG upon deployment during the use phase. The beach and ocean clean-up operations cumulatively remove around 100 tons of ALDFG, resulting in the stockpiling of 300 tons of ALDFG every year from the commercial fishing practices alone. Additionally, MFA reveals that about 4200 tons of waste FGs are collected at the waste management facilities in Norway, out of which only about 50% are segregated and sent for further recycling, whereas 25% are sent to landfilling and for incineration purposes within Norway.

17.3 Application of MFA in the Context of the Circular Economy and Sustainable Development

MFA is routinely applied at multiple levels of governance. At the national level, economy-wide Material Flow Accounts are reported annually by the EU-27 to Eurostat. These accounts are in turn used as indicators of progress towards the EU's Circular Economy Action Plan, such as circularity rate (CGRi 2021), recycling rate, etc. MFA is also used as a methodology to calculate progress towards multiple indicators to meet the SDG targets. For example, MFA is used to calculate progress towards a decoupling of the economy from the material footprint in SDG 8, target 8.4 through material consumption and production rates. At the city level, MFA is a standard methodology for calculating the flows of material and energy through different sectors within a city. MFA can highlight opportunities for cross-sector collaboration, whereby the material output from one sector can be utilised by another (Kick-starting circular cities and regions in Scotland: Glasgow (Del Sordo 2019).

Furthermore, the ISO 14000 series on Environmental Management now includes two standards for Material Flow Cost Accounting (a version of MFA which includes calculation of economic costs of energy and material flows), ISO 14051 and ISO 14052. The ISO standards have now set up a technical committee for the development of circular economy ISO standards which may also include reference to the MFA methodology. Several studies, including regional and industrial sectoral analyses, highlight MFA-based studies' application to define pathways toward circularity (Franco 2017; Huysman et al. 2017).

The case of fishing gear presented here is a good example of an industry/sector level MFA and further illustrates how findings from MFA can aid informed decision-making at the regional level. Table 17.1 illustrates how MFA is calculated and utilized by different stakeholders across the life cycle of fishing gear and provides possible applications resulting from the MFA data. This type of MFA is beneficial for a range of actors in the fishing gear value chain (Table 17.1). Private sector actors, such as Gear Producers, benefit from information on the market demand for fishing gear. Regulatory bodies are provided with information on the hotspots for fishing gear losses to the environment. Environmental non-governmental organizations (NGOs), such as beach cleaning groups, benefit from data on the effectiveness of clean-up programmes.

Stakeholder Dependency for Data Collection

MFA requires intensive data collection from key stakeholders. As MFA maps the system life cycle of a selected product/process and tracks the material of interest from production to its end of life, it demands quantitative and qualitative information from various actors involved directly or indirectly with the system under consideration (Deshpande and Haskins 2021). Therefore, practitioners must invent or adapt methods to extract information from resource users, regulatory actors, published or unpublished literature, datasets, waste management companies, and other relevant information providers. Table 17.1 illustrates how the information was gathered in the case of FG resource management in Norway and which stakeholders were involved.

Systematic monitoring and availability of data on material and energy streams by government and private actors would help to make MFA more accessible to companies. Academia and the private sector can work to develop more accessible software for companies. Industry-relevant research, such as the research in this case study, is a valuable source of information for businesses across the value chain. However, it is essential that research is made accessible to the private sector through open-source publishing.

17.3.1 Practical Possibilities and Obstacles for Companies for Using MFA

Any company can use MFA for mapping energy and material footprint. The information that MFA provides companies with, can help them map where they are losing energy and material from in their value chain. This in turn, can be used to develop a circular economy and sustainable development targets. Data availability is a barrier for applying MFA at the company level resulting in higher costs initially.

Conducting MFA, therefore, may prove time and resource-consuming, but in hindsight, it provides a holistic understanding of the various processes and systems that further aid in developing policies for sustainable resource management. Table 17.1 summarizes information obtained from MFA results for each stakeholder group and how these groups can apply the findings from MFA to improve the system of FGs in accordance with the CE strategies.

17.4 Concluding Remarks

As discussed in Part II, the MFA tool provides in-depth understanding of the various processes and causative factors across the system life cycle of the selected resource/substance. The need for quantitative information demands integration of all the necessary tools and scientific methods (qualitative and quantitative) to obtain data essential to model the processes within the given system. The relevant information, if absent, in official documentation or databases, must be obtained through field visits and subsequent contacts with the stakeholder groups which further improves the understanding of the resource system. The data collection procedures, implemented to gather essential information from fishers and associated challenges and benefits are summarized in Deshpande et al. (2019).

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Chapter 18
Environmental Management at Fiskerstrand Verft AS: A 30 Year Journey

Rolf Fiskerstrand and Annik Magerholm Fet

Abstract Fiskerstrand Verft is a multipurpose shipyard with extensive expertise and activities in shipbuilding, maintenance, repair and conversion/modification of ships. The yard is exposed to a range of different environmental challenges related to its business which trigged the yard to develop and implement health and safety, and environmental management systems. This chapter gives an overview of environmental management at Fiskerstrand Verft over a 30-year period, written from the perspective of the first author as CEO. The activities from 1991–94 mainly considered Level 1 in the CapSEM Model with annual accounting of materials and wastes, emissions to air and discharges to ocean. The yard participated in various R & D environmental projects and during the period 1994–99 these were extended with activities corresponding to life cycle thinking according to Levels 2 and 3. In 1999, Fiskerstrand Verft was the first Norwegian shipyard that prepared and published an environmental report. The yard was certified as an environmental lighthouse company in 2000, the first in Norway. During the period 2004–2008, the yard further developed their systems and began to transition to Level 4. The life cycle perspective for ships and technology has been at the center of the development of green technologies for ships. This journey continues today, passing the 30 year mark, and has contributed invaluable knowledge about the CapSEM toolbox and how it can be applied to shipyard operations.

18.1 Introduction

Fiskerstrand Verft AS is a shipyard established in 1909, located in the municipality of Sula, Norway about 25 km from the center of Ålesund. More than 112 years later, Fiskerstrand Verft is a cornerstone company: a multipurpose shipyard with

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extensive expertise in shipbuilding, maintenance, repair and conversion/modification of ships. Our business has always been based on quality, expertise and reliability.

Since 1965, Fiskerstrand Verft has delivered more than 84 new ships. Over the years, Fiskerstrand Verft has also provided innovative and safe solutions for fishing vessels, and car and passenger ferries in order to achieve the best solutions for our clients. Fiskerstrand Verft has extensive experience in vessel modifications; its main focus is on using the latest knowledge, working methods and technology in modern facilities.

Over the years, we have also gained solid expertise in environmental technology and have, amongst other things, had a particular focus on liquefied natural gas (LNG) engines for ships, battery technology and on the potential for hydrogen-powered ships. In 2019, Fiskerstrand Verft invested in a new and larger floating dock and increased the docking capacity from 6000 tons to 12,000 tons. The dock opened the potential for new markets at the same time increasing efficiency: it has facilities that ensure the collection of wastewater, chemicals and oil which help the yard to better control waste which in turn helps to protect the environment.

The mother company, Fiskerstrand Holding AS, consists of three 100% owned companies Fiskerstrand Verft AS (shipyard), Fiskerstrand Eiendom AS (property company), and Multi Maritime AS (ship design, consultancy company). Our vision is to 'create sustainable maritime development'. This vision is underpinned by our values, of 'Quality, Reliability, Inclusivity and Innovation', and our business focus is primarily on European markets through projects based on green technology and sustainable solutions. Fiskerstrand Verft runs the entire business in an environmentally friendly way. The shipyard will always follow laws and regulations and strive to find new solutions in the fight to reduce emissions and waste, as long it is financially defensible. This, amongst other factors, requires a constructive companionship with our clients, suppliers, and business partners. We wish to prioritize and open channels of communication with our employees, local society, and national government regarding environmental issues.

18.2 Environmental Challenges

Fiskerstrand Verft is exposed to a range of different environmental challenges related to its business. It has a dynamic and thriving variety of activities in general and as a natural part of various ongoing projects. It generates large volumes of waste some of which are dangerous. There is significant time pressure while executing projects: particularly during the construction phase. All of this is accompanied by an increasing focus on the environmental impact of such projects and on requirements to resource efficiency in society.

The most significant environmental impacts result from outdoor repairs, maintenance and conversion work while the ships are in the dock or at the quay side. The environmental impacts discussed in our reports primarily affect local or regional areas. Fiskerstrand Veft has been producing annual 'Environmental reports' since 1999 that show, among other items, energy and water consumption, emissions to air, land and sea, amount of waste and materials to recovery and recycling.

18.3 Environmental Management at Fiskerstrand Verft

Fiskerstrand Verft intensified their work with managing health, safety and environment (HSE) in 1992 to improve their performance regarding procedures for working processes to HSE-issues. The text further gives a flavor for the work throughout the following years. Many of the results achieved in this time period were documented in internal reports and the following research reports for the projects conducted in cooperation with Møreforsking Ålesund (www.moreforsk.no/):

Rapport Å 9406, Prosjekt nr. 5707.
Rapport Å 9501, Prosjekt nr. 5713.
Rapport Å 9502, Prosjekt nr. 5706.
Rapport Å 9615, Prosjekt nr. 5734.
Rapport Å 9506, Prosjekt nr. 5707.
Rapport Å 9616, Prosjekt nr. 5734.

In 1992, a new '*Forskrift om internkontroll'* (Regulation for internal control) was introduced by the Norwegian government in order to improve companies' activities in relation to working environment and safety, protection concerning health and environmental damage from products and the protection of external environment against pollution and a better treatment of waste. The shipyard used the rebuilding/conversion of the car- and passenger ferry M/S 'Smørbukk' as the basis for the project. The work was carried out at the yard in 1992 and documented used materials, work activity for the rebuilding, quantity and type of waste. Material flowcharts then illustrated the total amount related to the rebuilding.

In 1993, based on this new regulation, Fiskerstrand Verft prioritized the work with the environmental management system (EMS). Whilst undertaking this work, we realized that assistance from experienced specialists was required.

In 1994, Fiskerstrand Verft was invited to participate in the project 'Cleaner production in the shipyard industry in the County of Møre og Romsdal', a collaboration between 5 shipyards in the region. This project looked at bottom hull treatment, paint and metallization of steel materials, waste disposal when rebuilding or converting vessels, sand blasting new steel materials, or painted steel materials.

The purpose of this project for Fiskerstrand Verft was to identify the potential for cost effective environmental improvement based on the introduction of cleaner production at the yard, as well as introducing improvements in the choice of materials and equipment to reduce waste and improve the impact on the environment. The project also investigated the possibility of reducing the amount of materials, result of dangerous waste and possible recycling of materials and waste. Fiskerstrand Verft was responsible for the work related to waste disposal when rebuilding vessels.

In 1994, as part of the project, Fiskerstrand Verft proposed the following improvements and rectifying actions:

1. Improved handling and labeling of waste, especially hazardous waste.
2. Recycling of thinners.

3. Source sorting of solid waste.
4. Development and implementation of computer programmes for substance indexes and environmental accounting.

The assumed environmental impact the individual rectifying actions might have on the amount of material, energy consumption, water consumption, construction activities, waste and contamination were all evaluated. The consequences related to economy, results, time and manhour consumption were also evaluated for the different proposed rectifying actions. Based on this, we commenced a thorough update of our environmental management system, environmental strategy, environmental mapping, goals and programmes.

The activities from1991–1994 mainly considered Level 1 in the CapSEM Model. All tools (I/O and Cleaner Production) were used to collect quantitative information. By developing this further, a database for the environmental aspects for shipyards was created. In 1994, a report was produced regarding the systematic assessment of environmental aspects for ships in the design, engineering, construction and operational phase seen in a cleaner production perspective. This system documentation identifies the limits of the total system and subsystems.

As a second step in the portfolio of projects that followed the cleaner production project in the period 1995–96, were the following projects: (i) "Waste minimization at shipyards," (ii) "Bottom hull cleaning water treatment at Liaaen Verft," (iii) "High pressure water blasting at Fiskerstrand Verft." and (iv) "Enclosed systems for sandblasting at Ulstein Verft (black steel) and at Søviknes Verft (painted steel)." These activities correspond to changes towards less polluting practices. One of the activities corresponding to Level 2 in the CapSEM model, was a project where the life cycle assessment (LCA) was tested by a simplified analysis. Life cycle screening (LCS) of the cruise ferry Color Festival was studied to look at how to bring the information about the environmental impacts of the different subsystems into the design specification of new ferries by the design for environment (DfE), or design for x-principles (DfX) in ship design. As part of the EMS-activities corresponding to Level 3 in the CapSEM Model (see Fig. 18.1), a set of environmental

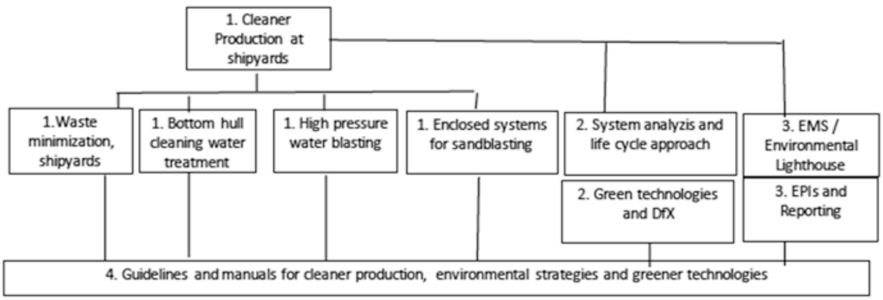

Fig. 18.1 Overview of activities resulting from the Cleaner Production project started in 1993. The numbers in the boxes reflect the Levels in the CapSEM model (modified from Fet 2002a, b)

performance indicators (EPIs) was developed and used to monitor and report the identified environmental impacts over time.

As seen in Fig. 18.1, the results from the projects noted under the numbers 1, 2 and 3 were collected and modified into guidelines and manuals for cleaner production at shipyards, and other inputs to policy programmes for greening of the maritime industry (Angelfoss et al. 1998, Fet and Sørgård 1998, Hayman et al. 2000, Fet 2001, Fet 2002a, 2002b, Fet and Zhou 2002, Ellingsen, Fet and Aanondsen 2002, Zhou et al. 2003).

In 1997–98, in connection with the introduction of preventive environmental measures, internal investment was carried out on environmental management systems (EMS) with a strong emphasis on the process Plan-Do-Check-Act (PDCA). This was based on the most significant international environmental management standards in the ISO 14000 series. A special attention was given to the standards for Environmental Management System (EMS), Environmental Auditing (EA), Environmental Performance Evaluation (EPE) and Environmental Performance Indicators (EPI).

Measuring environmental performance provides a basis for how good or bad a company is in relation to the most important environmental aspects and evaluated according to EPIs mirroring the efforts of achieving the best improvement. It also bench-marked the company's performance against comparable businesses. EPIs are used to measure environmental performance for aspects as usage of materials and energy, emissions to air, discharges to water and soil pollution. Different waste indicators and accident indicators are among the EPIs recommended in the report.

The database from the mapping of waste generated by conversion of M/S "Smørbukk" at Fiskerstrand Verft was used in this report. It represented a step forward in assisting and improving environmental performance for yards in general. The report also presented indicators for bottom hull treatment as well as emissions to air caused by painting and mentalization. Fiskerstrand Verft has prioritized since the early nineties, reducing the impacts on the surrounding environment.

In 1998–99 the EMS was further developed. Routines for documentation and reporting were developed and formalized. In 1999, Fiskerstrand Verft was the first Norwegian shipyard that prepared and published an environmental report (https://www.fiskerstrand.no/). As a result of several years of work with environmental performance improvements, the company was certified as an environmental lighthouse company in 2000, the first in Norway. This means that the company's criteria for both new building of ships, conversion and repairing of ships at shipyards are fulfilled. Annual environmental reports have been produced since 1999 up to 2012. For the period 2013 to 2018 a report showing the development over the period of 6 years is published, and since 2019 the report has been adjusted to highlight the yards' responsibility with respect to the 17 sustainable development goals (SDGs).

From 2004–2008, the yard further improved the EMS Manual. The Manual describes and document the yards system and covers the legal basis, organization and responsibilities, working environment and environmental protection, fire, explosion hazards and accidents, product control, reporting, protection inspection and damage reporting risk assessments, action plans, EMS revision reports and plans and materials register.

The EMS was also included in the Quality Assurance Manual (QAM). Working with EMS requires involvement, patience, working step by step and gradually education all those involved. The benefits of so doing are clear. It results in a long process forward to a "self-propelled system" (Procedures, training, maturing, posture etc.) provides an improved and tidier working environment. It established an environmental protection system (external environment) with 13 new forms and 22 procedures, sourced and sored (18 types) to yield financial gain due to a differentiated tax system for waste collection. Not least, the crew on board ship often display a "hands off" self-waste approach, which is at times a challenge.

The continuing work with the EMS manual and the integration of procedures according to the environmental policy, has contributed to a set of KPIs and reporting practices in line with a few of the tools that are listed for Level 3 in the CapSEM-model. As a "front-runner" within the shipbuilding and ship repair industry, the actions also have given an impact on a broader societal system, meaning a move from Level 3 to Level 4 in the CapSEM-model.

18.3.1 Level 4: Activities

The work with the environmental management provides valuable statistics and experience data. Fiskerstrand Verft was ordered in 2009 by the County Governor of Møre og Romsdal to undertake environmental surveys of the shipyard area and at the seabed near the yard. Multiconsult was engaged to carry out environmental geological survey of the yard area, field survey, risk and action assessments. The business then turned its focus to Level 4 in the CapSEM model, looking into the sector's impacts on the society from a broader perspective. The emphasis was on marine pollution and possibilities for improvements.

During 2007, Fiskerstrand Verft was invited to participate in the project "Opticap", a research project to increase knowledge about materials and practical methods suitable for capping contaminated marine sediments and to reduce spreading pollution. The project was a collaboration between NGI, NIVA, Agder Marine, Hustadmarmor, Secora, Fiskerstrand Verft and NOAH. Project management was driven by NGI. Fiskerstrand Verft supported the project financially with over one million NOK. The contract was between Opticap project group and Fiskerstrand Verft and Research Council of Norway. The project concentrated on investigating the development of fine-grained pumpable masses in moderate current-exposed seabed areas, measuring the effect of thin covering in relation to reductions in water concentration and pollution, measuring biota and recolonization after covering and documenting the effect of both passive and active covering of materials over time.

In this field test, a thin covering with suspended calc (biocalc) from Hustadmarmor and suspended calc mixed with activated charcoal (AC) on a heavily polluted area with among others Tributyltin (TBT) was employed. The test field, an of area

11000m^2 divided into two sub-areas, comprised one area of 9000m^2 covered with suspended biocalc alone, and one area of 2000m^2 covered with AC mixed with biocalc. The covering was carried out in September 2010. A total of 950 tons of biocalc and 5 tons of AC were used for the covering operation (Opticap 2012a). A final report “New materials and methods for laying out thin covering on contaminated seabed” was published in 2012 (Opticap 2012b).

Over the period of 2013–2021, Fiskerstrand Verft has also assisted other shipyards in developing their EMS as well as building competence in HSE. In addition, Fiskerstrand Verft has installed a number of electrical shore connections which provide an electrical power supply connection between the quay and/or the floating dock to the ships to ensure electrical supply onboard, thus preventing ships from using diesel engines with generators to obtain electricity onboard. The total shore connection capacity is 4000 kVA based on 400 V and 690 V, 50 Hz. From this capacity, 400 V and 690 V, 60 Hz can also be delivered, as required. Fiskerstrand Verft has been working with the Tafjord Energy Arena since 2015 on energy management (2015–2016) for industry and plant and energy savings (2016–2019) for buildings. Four main gauges on electrical intake, 2 sub gauges and 28 gauges for electrical consumptions were installed in 2020. The purpose is to monitor the electrical consumption to optimize and reduce peaks and thus, reduce both energy consumption and costs. The electrical grid rent is defined by the specific hour in a month with the highest power peak. It is therefore important to control power during any given period. The installed equipment is a good analytical tool to optimize control and thus reduce power peaks and costs.

18.4 Ship Building, Conversions and Repairs

The activities described in this section describe the use of the toolbox described for Level 2 in the CapSEM Model. During the period (2010–2021) the yard has focused on the development of green technologies, both to ensure a good practice in the organization, but also green technologies for ships. The life cycle perspective for ships and technology has been central, hereunder focusing on the suppliers for equipment to development of greener technologies. From this point on, the yard has been concentrating on product improvements according to Level 2 in the CapSEM Model. This work took a life cycle approach where both upstream and downstream activities were considered (use of materials, technologies in the building process and impacts from the operating vessels). One example from 2002 is the car- and passenger ferry “Nordfjord”, which was the third ship in world history built under the environmental classification notation “Clean Design”, which has strict requirements concerning safety and waste handling and promotes minimizing emissions to sea and air.

In March 2013, the LNG-bunkering vessel “Seagas” was delivered, the world’s first dedicated LNG (liquified natural gas) bunkering vessel that can deliver LNG from ship to ship. It was based on a conversion of the car and passenger ferry

“Fjalir” to serve the Ropax ship “Viking Grace” for the line from Stockholm – Helsinki. Since 2010, six ships based on LNG-engines were delivered. This included one based on LNG hybrid battery and one based on biodiesel hybrid battery. Fiskerstrand Verft also delivered the conversion of a ferry from LNG to hybrid with battery, two ferries from diesel to battery and one from LNG to battery. Table 18.1 presents an overview of green technologies installed in vessels delivered by Fiskerstrand Verft.

18.5 Development of Green Ship Technology

In December 2016, Fiskerstrand Holding AS was granted support by the Pilot–E system to develop a conversion of a car- and passenger ferry from diesel engines to a hydrogen fuel cells hybrid battery system. Pilot-E is a financing scheme for Norwegian industry, established by the Research Council of Norway, Innovation Norway and ENOVA.[1] The project was named HYBRIDship (Cf https://www.sintef.no/prosjekter/2017/hybridskip/). The overall idea of the project is to realize zero emission propulsion systems for longer crossing/operation time and larger vessels in hybrid configurations based on battery and hydrogen technology. Based on this knowledge base a pilot project for a hybrid ferry (hydrogen/battery powered) was outlined and specified. Further, an existing car- and passenger ferry should be rebuilt and tested by end of 2020 as the first car- and passenger ferry in commercial operation in the world. Both DNV and Norwegian Maritime Authority were partners in the project for the purposes of approving/validating the process. The objective was a win-win situation for both the regulating authorities and the yard in order to ensure pioneering functions.

Unfortunately, the project was terminated due to lack of financing for the ferry conversion. Battery will become the main source for ferry fjord crossings of up to 45–50 minutes. Hybrid with hydrogen and battery are more appropriate for fjord crossings for longer distances. Hybrid with batteries and biodiesel/biogas could also be used. Hydrogen fuel cells hybrid battery are relevant for the aqua industry, short sea shipping–cargo, local cruise lines–fjord cruises, local fishing vessels, high speed catamarans and supply and service vessels for offshore industry and offshore windmills.

Fiskerstrand Verft has installed an advanced system for managing wastewater from the high-pressure bottom hull cleaning of ships in the dock. The flush-down-water contains paint residue like TBT, PCB, seaweed, seashells etc. The water cannot be pumped directly into the sea. Six compilation wells for wastewater have therefore been installed: - two in each end and two in the middle of the dock. Collection pipes are installed in the bottom of the dock leading up to four pumps which pump this through a pipe on the seabed to 3 large settling tanks on the quay.

[1] Enova SF is a Norwegian government enterprise responsible for promoting environmentally friendly energy production and consumption.

Table 18.1 Overview of green technologies installed in vessels delivered by Fiskerstrand Verft

Vessel type	Name	Power system	Description	Category	Year
Ferry	Selbjørnsfjord	LNG	A pioneering project, installing a gas electric system in a car ferry, replacing traditional diesel driven system significantly reducing NOx and CO2 emission.	New building	2010
Ferry	Boknafjord	LNG + diesel	At the time, the world largest LNG driven car ferries crossing Norwegian fjords. Modern LNG engines, combined with diesel and SCR cleaning, gives a significant NOx – CO2 and methane reduction.	New building	2011
Feed ship/ aquaculture	With harvest	LNG	Gas mechanical directly driven propulsion system, optimized for low resistance at sea and low emission.	New building	2014
Feed ship/ aquaculture	With marine	LNG	Gas mechanical directly driven propulsion system, optimized for low resistance at sea and low emission.	New building	2014
Ferry	Hasvik	LNG	Gas electric propulsion system, hull optimized for low resistance at sea and low energy consumption	New building	2015
Ferry	Bergsfjord	LNG	Gas electric propulsion system, hull optimized for low resistance at sea and low energy consumption	New building	2015
Ferry	Fannefjord	LNG/ battery hybrid	Car ferry, upgraded with batteries to handle load transients for reduced use of LNG engines.	Retrofit/ Conversion	2015
Ferry	Hornstind	Biodiesel/ battery hybrid	Car ferry with batteries installed to handle load transients by reduced use of diesel engines. Diesel engines can run 100% on biodiesel, including exhaust cleaning systems, Hornstind achieves significant reductions in CO2 and NOx emissions.	New building	2017

(continued)

Table 18.1 (continued)

Vessel type	Name	Power system	Description	Category	Year
Ferry	Årdal	From diesel to battery	Diesel electric ferry upgraded to 100% battery electric propulsion system. Ferry is adapted to charging systems from shore for fast charging and shore power for reduced use of diesel generators at rural locations.	Retrofit/ Conversion	2019
Ferry	Lærdal	From diesel to battery	Diesel mechanical ferry upgraded to 100% battery electric propulsion system. Ferry is adapted to charging systems from shore for fast charging and shore power for reduced use of diesel generators at rural locations.	Retrofit/ Conversion	2019
Ferry	Karlsøyfjord	From LNG to battery	Gas electric ferry converted to 100% battery electric propulsion system. Ferry is adapted to charging systems from shore for fast charging and shore power for reduced use of diesel generators at rural locations.	Retrofit/ Conversion	2022

Finally, the water on the upper part of the settling tank is then pumped to a purifier plant securing clean water. The dregs from the settling tank are taken out regularly and treated as contaminated substance. The upgrading of the dock represents an improvement on Level 1 in the CapSEM model by reducing discharges to the sea from one of the operation processes at a maintenance shipyard.

18.6 Conclusion

This case study describes a transition toward sustainability that has taken place over a period of 30 years, beginning with the application of Level 1 of the CapSEM model, moving to Level 3 with implementation of EMS, KPIs and reporting. The understanding of the impact from shipyards on the environment matured over time, accompanied by a better comprehension of environmental impacts from each phase of the life cycle of the ship. When Level 3 in the CapSEM model was reached, a distinct and measurable shift in performance was demonstrated based upon results from environmental accounting obtained over a long period of time. This change is reflected and documented throughout the annual reports. The activities described for Level 4 illustrates further that Fiskerstrand Verft had gained valuable knowledge and experiences applicable to the entire the shipyard industry, e.g., as the pilot company developing the set of criteria for shipyards to become Environmental Lighthouse certified. The heavy involvement in the conversion to greener technologies also demonstrates how important the understanding of the life cycle performance of products is, both in the design of the technology and the impact it has over the life-time operation and maintenance of the vessel. A further attention to circular economy principles in the shipping industry, will gain more attention in the future. This requires close collaboration with the shipowner and the shipyard. This 30-years journey has also provided knowledge about the CapSEM toolbox and how the various methods can be used for different shipyard operations, as demonstrated by the example with the upgrade of the floating dock. The environmental accounting for this follows the input-output calculation method and the principles for cleaner production at Level 1.

In closing, this case is an example of how early environmental strategies, combined with practical work and visionary leadership, can lead to the greening of the shipyard industry.

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Chapter 19
A Transportation Planning Decision Support System

Dina Margrethe Aspen

Abstract In this chapter, the CapSEM toolbox is explored, applied, and evaluated in the context of transportation planning and policy-making. Transportation system elements are analyzed across all four CapSEM levels to identify relevant tools to utilize in decision support systems to address sustainability in the sector. The toolbox is applied to a strategic transportation planning case study. The application demonstrates how the framework may be used to structure and stack models across system and performance levels to handle transportation modeling and stakeholder complexity.

19.1 Introduction

The transportation sector provides critical mobility services to society, ensuring the movement of goods and people. However, the sector also significantly impacts the global and local environment. The sector accounts for 24% of global direct CO_2 emissions from fuel combustion (IEA 2020) and has increased its annual greenhouse gas emissions faster than any other societal sector since 2010 (IPCC 2022). Transportation also contributes significantly to NO_x emissions that may have adverse health effects. In Europe, the sector accounted for 55% of all NO_x emissions in 2017 (EEA 2019). Appraising sustainability performance and improvement pathways requires tools that handle the scale and complexity of transportation systems. This entails addressing sustainability across multiple systems and domains in providing holistic appraisals to support planners and policy-makers. The Capacity Building in Environmental and Sustainability Management (CapSEM) toolbox offers structure and methods for addressing sustainability across variable system and performance levels. In this chapter, the CapSEM toolbox is explored, applied,

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and evaluated in the context of transportation planning decision support systems (DSS). A case study is provided to determine its value and contribution to analyzing and solving complex sustainability challenges in the sector.

19.2 Exploring the Toolbox in the Transportation Sector

The CapSEM toolbox organizes approaches to appraise sustainability across process, product, organizational and system levels (Fet and Knudsen 2021). Each level has its distinct system and performance scope: Ascending across the four levels of the framework implies moving from low to high system complexity and narrow to broad scope of sustainability performance (Fet and Knudsen 2021). In transportation planning, multiple levels often need to be addressed simultaneously as technical, operational, and system-wide conditions need to be viewed in concert to understand the implications of transportation policies.

Table 19.1 lists elements to address improving the performance of transportation systems and associated tools for assessing them. Process change (Level 1) concerns production processes in the studied system (Fet and Knudsen 2021). Critical processes in transportation systems concern energy conversion to produce transport work. The inputs and outputs from these processes significantly impact the environment, particularly through resource depletion and air emissions. In order to assess the consequences of alternative energy carriers, conversion and abatement technologies, input-output based models are necessary.

At the product and value chain level (Level 2), the scope increases beyond operational impacts to include upstream and downstream impacts. At this level, additional input factors beyond energy carriers to produce transportation services such as materials, chemicals, and other consumables are also important. Life cycle assessment methods may be used to evaluate alternative transport options to avoid temporal or spatial problem-shifting of environmental and other sustainability impacts.

At the organizational level (Level 3), managerial and operational concerns are addressed, extending from processes and product systems to also encompass human behavior. Therefore, aspects related to economic and human factors must also be

Table 19.1 The CapSEM toolbox for transportation system sustainability appraisal

CapSEM level	Unit of study	Tool
Process	Energy conversion, e.g., engine combustion	Input – Output analysis
Product	Fuels, materials and chemicals	Life cycle assessment
Operational	Route choice, speed and technology deployment	KPIs, OPIs, preference modeling
System	Regulation and policies at regional level	SE, system analysis

considered at this level (Fet and Knudsen 2021). This may be translated to the operational features of the transportation system. The decisions and actions of multiple actors combine to produce the total system behavior and, ultimately, performance. Actors' preferences and behavioral logics strongly influence their operation of transport technologies, such as choice of transportation modes, routes, and speed (Díez-Gutiérrez and Babri 2020). To assess improvement measures at this level, preference modeling, key performance indicators (KPIs), and operational performance indicators (OPIs) may be deployed along with models on lower levels to understand the effects operational measures.

Lastly, at the system level (Level 4), holistic transportation planning, policies and regulation are of key interest. This is critical as optimizing subsets of the transportation system may provide effects that counteract overall system performance improvement. Tools for systems modeling, design, and assessment are required to provide a holistic perspective in planning and policy making.

In addition to providing a useful system breakdown structure of units of study and associated tools, there is also a cumulative aspect of the value of the CapSEM Model when applied to develop decision support systems in transportation planning. Information and knowledge retrieved at any level is relevant to inform higher levels. For instance, a life cycle assessment (Level 2) of alternative fuels also requires considering their combustion process characteristics (Level 1). A transportation system assessment (Level 4) requires a model that captures the system dynamics in a defined area where information from all previous levels (Levels 1–3) is included.

19.3 Application to a Transportation Planning Case Study

To illustrate the application of CapSEM, a case study from the Geirangerfjord World Heritage Site area is used, where authorities and transportation system actors need to balance the economic, social and environmental impacts related to tourism in the area. In 2018, the Norwegian parliament adopted a zero-emission regulation for ship traffic in the Norwegian fjords designated as world heritage sites by 2026 (Stortinget 2022). The resolution posed a complex problem to stakeholders in the Geirangerfjord area as it entailed technological, economic and logistical challenges. This required multiple actors to jointly assess alternative strategic responses to meeting the zero-emission requirements. As the transportation system includes land and sea traffic related to regular and tourist-based activities, the assessment rapidly increased in complexity. In order to provide a system-level assessment, tools from all levels in the CapSEM toolbox were utilized to build a holistic decision support system. Figure 19.1 shows the DSS resulting from this application, which is further elaborated in subsequent sections.

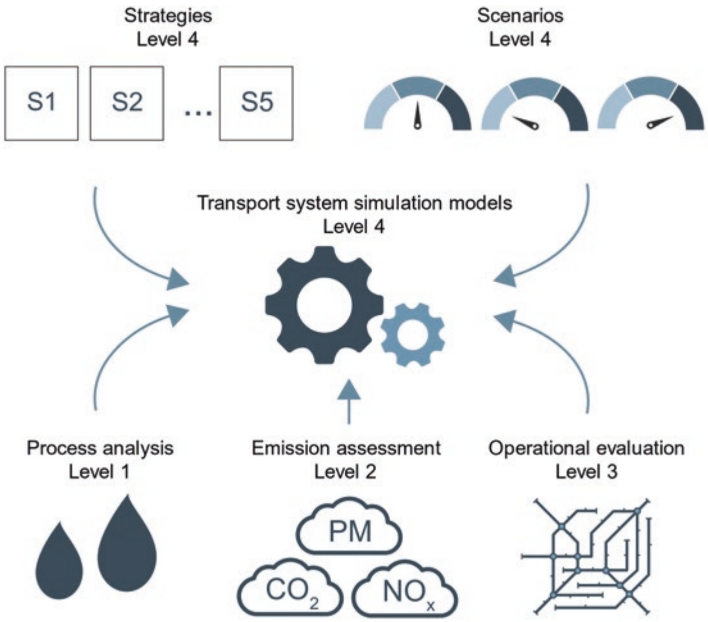

Fig. 19.1 Models and tools in the transportation planning decision support system across CapSEM Levels

19.3.1 Using CapSEM Tools to Develop DSS for Transportation Planning

The system-level responses to the regulation require structuring and modeling decisions and scenarios involving multiple actors. To establish a joint problem statement, the SPADE methodology was used. SPADE is a soft systems engineering approach valuable in handling complex problems in multi-actor environments (Aspen, Haskins, and Fet 2018; Haskins 2008). The methodology was applied to identify stakeholders (S), problems (P), and alternative strategies (A) to synthesize a decision analytical structure (D) for further modeling and evaluation (E). The stakeholder analysis helped classify key actors to include in the subsequent problem formulation. These included cruise companies, port authorities, transport companies, tourist operators and politicians. The problem formulation helped structure strategic responses to the regulation and identify uncertainties, scenarios, and key performance indicators to use in the subsequent modeling and analysis.

Next, a transportation system simulation model was established. As both road and sea traffic would be affected by the zero-emission resolution and respond interactively to alternative strategic actions taken, two separate models were developed and connected to assess the overall dynamic system response. The land traffic model handled all transport on road links in the area and included a module to specify cruise characteristics. The sea traffic model handled cruise ship activity and local ferry transport. The combined model made it possible to estimate sustainability performance metrics such as air emissions and traffic congestion. More elaborate information about transport models and parameters may be found in Díez-Gutiérrez and Babri (2020, 2022), Johansen (2021) and Johansen, et al. (2021).

In order to estimate air emissions in a holistic simulation model, several components were developed using tools across levels 1–3 in the CapSEM toolbox. Firstly, models were developed to predict operational responses (level 3) to various perturbations in the transportation system. This entailed addressing traveler preferences and impacts on e.g. route choice (Díez-Gutiérrez and Babri 2022). On this level, models to derive energy consumption for various operational patterns in road and sea traffic were also established (Aspen, Johansen and Babri 2020). Life cycle inventory data was used to establish emission factors (Level 2) from alternative fuels in sea traffic (Winnes and Fridell, 2010). Lastly, process models (Level 1) to derive emissions for various operational profiles, fuels, and abatement technologies were created (Aspen et al., 2020, Johansen 2021, Johansen et al. 2021).

The four-level approach enabled holistic and comprehensive analyses and evaluation of strategic policy responses for key transportation actors. The comprehensive study included assessment criteria across all sustainability dimensions, but for simplicity, a truncated illustration of the decision support system and associated tools deployed is shown in Fig. 19.1.

19.3.2 Insights Gained from Model Deployment

The application of systems engineering (Level 4) provided several problem structuring elements, such as definition of system boundaries, key stakeholders, a specified set of strategies, scenarios, and performance evaluation criteria. Figure 19.2 shows the study area with the strategic transport responses to the new regulation from the multi-stakeholder group consulted. Through their engagement, five main strategies were defined to explore transportation patterns for visitors to Geiranger based on alternative cruise traffic routing. For all strategies, cruise ship emissions were calculated based on a configuration of marine gas oil with exhaust gas cleaning technology installed (SCR). Strategy 1 (S1) was to work toward business as usual (BAU) which represents the current situation where cruise ships call to port in Geiranger. This would require delayed enforcement or reversal of the parliament regulation. Strategy 2 (S2) was to work towards a dispensation for zero-emission sailing in a "blue corridor" within the world heritage area. Strategy 3 (S3) was to develop a new cruise port outside the world heritage area in the Stranda village. Strategy 4 (S4) was to take no action and make cruise ships call to nearby ports outside the world heritage area, while strategy 5 (S5) was to route cruise ships outside the entire area, visiting other sites than the ports within the study area. Within all scenarios, various combinations of land traffic (bus) and zero-emission

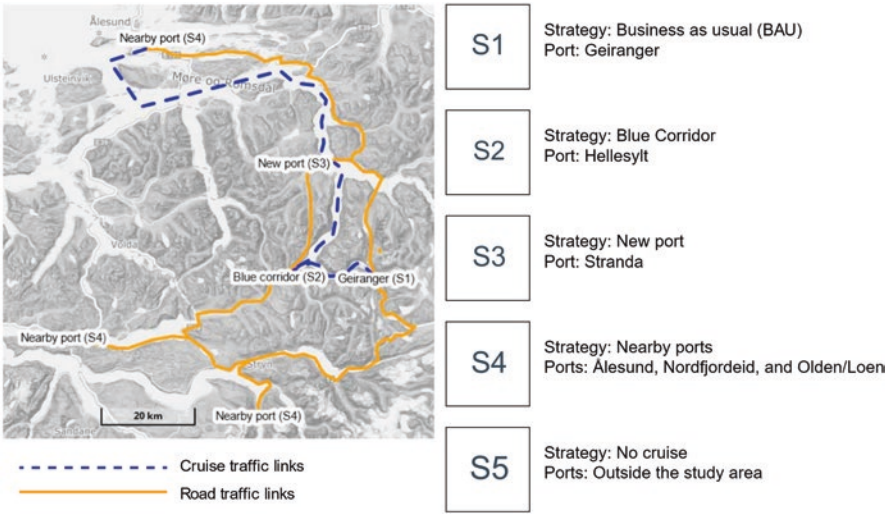

Fig. 19.2 Summary of boundaries and strategies defined in the problem structuring process. The map is created in the Norgeskart portal by ©Kartverket

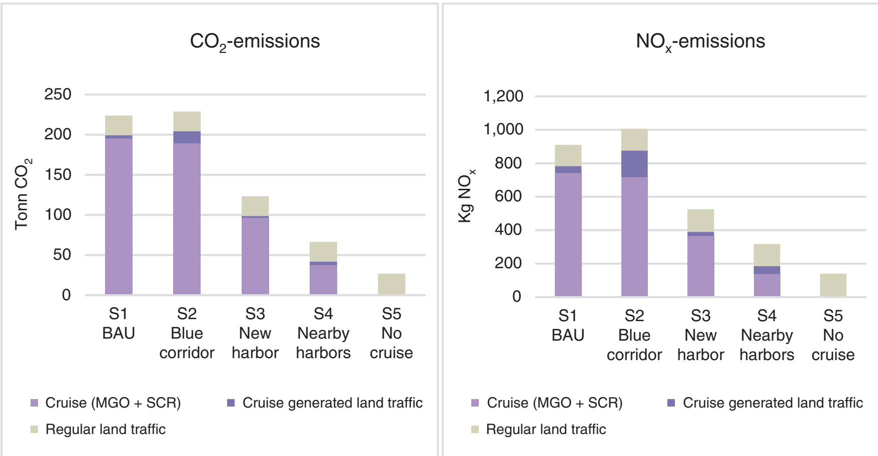

Fig. 19.3 Total CO_2 and NO_x emissions in the study area under a medium scenario

vessels to bring visitors to various sites in the Geiranger village were also computed. To account for uncertainties, scenarios for high, medium and low visitor volumes were also used when assessing strategies.

By deploying models at all CapSEM Levels, it was possible to assess the total transportation system performance across all strategies and scenarios. Figure 19.3 shows selected results from the broader sustainability impact assessment, displaying the CO_2 and NO_x emissions for a medium scenario where a bus roundtrip is assumed for visitors traveling between alternative ports and the Geiranger village. The figure illustrates that potential cruise-generated bus traffic would only contribute to a small portion of the total transport-related air emissions in the study area. This insight was critical as several stakeholders were concerned about problem shifting through the transferal of emissions from sea to land traffic. The analysis showed that emissions from road traffic were negligible compared to emissions from cruise ships and that cruise port location was of a greater importance.

Another critical parameter of concern was the potential for traffic congestion on road links in the study area due to cruise traffic rerouting. As cruise-generated bus traffic would increase significantly following strategies 1–4, an estimation of reduced speed compared to the respective speed limit was performed for each road segment under a maximum traffic scenario. The results in Fig. 19.4 show that the Blue Corridor strategy generated the highest level of congestion on road links in the

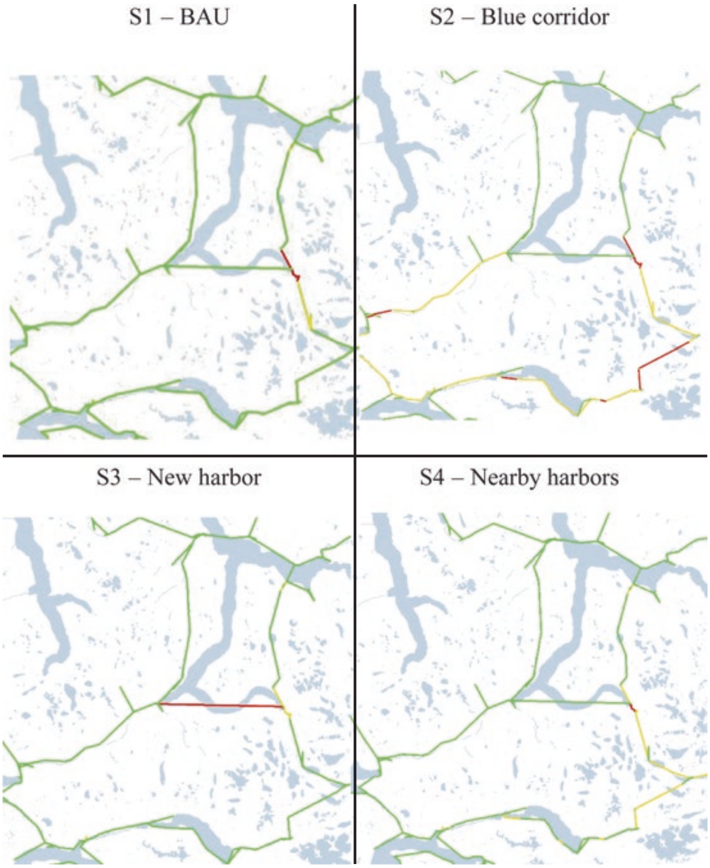

Fig. 19.4 Congestion on road links with cruise generated bus transport across strategies 1–4 under a maximum scenario. (*Green link*: no congestion, *yellow link:* medium congestion level, *red link:* high congestion level)

study area. For this strategy, it was evident that local transport between cruise port and the village had to be accommodated partially or wholly by sea transport compliant with the regulatory zero-emission requirement.

19.3.3 Concluding Remarks

In this chapter, the CapSEM toolbox has been explored and applied for developing a decision support system in the transport sector. The explicit formulation and combination of models within the four-level CapSEM structure proved useful in addressing transportation system sustainability issues in the case study.

From a modeling and analysis perspective, the CapSEM Levels helped organize a model breakdown structure in the DSS. The sustainability performance of the total transportation system depends on elements at all CapSEM levels: Physical input-output processes in energy conversion, techno-economic processes in product systems, the operational behavior of transport system actors and material, and strategic policy and planning processes at the system level. At the same time, models were designed to let information propagate through the layers facilitating increasingly complex inferences about the sustainability performance of transportation measures. This was convenient as it helped manage and exploit multiple domains and logics necessary to support transportation planning. It also made it easier to compartmentalize critical factors and assumptions in the model structure and keep track of key parameters and their sensitivities.

From the viewpoint of stakeholder engagement and interaction, the approach also facilitated a clear and transparent dialogue between analysts and various decision-makers on the data, assumptions, and reasoning at each system level. This is important to ensure stakeholder comprehension, judgment, and utilization of information and knowledge in transportation planning processes.

This case provides a simple illustration of how the CapSEM Model may be applied in the transport sector. While the chapter only focused on assessing air emissions from various responses to environmental regulation, several other sustainability aspects could and should be explored utilizing the CapSEM Model and associated tools. This includes other environmental impacts, such as land use and ecological impacts, as well as social and economic aspects influenced by various transportation system planning strategies.

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Chapter 20
First Steps Towards Sustainable Waste Management

Øystein Peder Solevåg

Abstract Waste management started off as a public health issue. Today, the waste business is an important force in developing sustainable development and circular economy. New policies and regulations represent an opportunity for circularity, but there is still a long way to go in achieving a truly circular economy. The Circularity Gap Report 2020 indicated that the global economy is only 8,6 % circular. Industrial ecology and material flow analysis are important tools, not only for developing local and regional waste solutions, but also in the development of new global circular business models. In the Ålesund region, new sorting measures have increased recycling, from 32 % in 2017 to 45 % in 2019. New measures will be needed to reach national targets set for 2025. As the current global use of resources is unsustainable, and as current waste business models are insufficient to achieve circular economy, the next decade is likely to experience a rapid innovation of new business models challenging traditional waste management companies. This chapter presents data collected during a case study conducted in 2020.

20.1 Introduction: The Historical Development of Waste Management

Historically, waste management was introduced as a public health measure in larger cities. Removal of waste, which was mainly of organic origin, was necessary to reduce the risk of vector induced disease, e.g., through vermin or drinking water. Removed waste was either diluted in city waterways or reused as fertilizer in food production, inside and outside nearby cities (Torstenson 1997).

As industrial production developed, new materials, chemicals and other by-products where introduced, and with increased knowledge on the detrimental effects of pollution on human health and the environment, the need for more complex waste management solutions became apparent. During the twentieth century, waste

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management was developed as an economic service, the *Waste Business* was established. This newly established business organised collection and transportation of waste, surplus chemicals og other by-products, as well as establishing landfills and waste incineration plants. For a few materials, such as metals, recycling systems were established (Bodamer 2018). This development is mainly seen in Northern Europe. Globally, several countries have not moved forward in at the same pace. Several developing countries have only to a limited extent developed systematic waste collection and treatment. Marine littering is a major consequence of lack of such systems worldwide.

20.2 Waste Management and Circular Economy

In the twenty-first century, two global trends are setting a new standard for waste management. First, the global effects of waste and waste management are recognized as crucial for sustainability. The interlinkage between global resources and sustainability goals gives birth to the concept of circular economy (BH4S 2022). Circular economy can be described as a system "where the value of products, materials and resources is maintained in the economy for as long as possible, and the generation of waste minimized" (Merli 2018:705).

In the years between 1990 and 2010, cleaner production methods were applied to achieve process optimalisation in the waste management business. Towards 2010, life cycle assessment was applied as a planning and decision tool for the development of new recycling solutions (Michaud 2010). As the waste management sector was consolidating, environmental management systems were applied. Extended producer responsibility has also been implemented as a tool to organise and finance waste management (Kunz et al. 2018), as has eco-design (Demirel and Danisman 2019).

There are several methodologies and indicators used to describe the circularity of the economy. The Circularity Gap Reporting Initiative (CGRi) is an initiative of Circle Economy, an impact organisation dedicated to accelerating the transition to the circular economy (CGRi 2020). Using material flow analysis, this Initiative has published global and national reports on circularity. It describes several dimensions of the global material flow. Firstly, it describes the total amount of materials applied, based on material type (minerals, ores, fossil fuels and biomass). Then the material flow through the global economy (take, process, produce, provide, end of use) is described. The share of the global material flow between global business sectors (housing, communication, mobility, healthcare, services, consumables, and nutrition) is also described. Of the 100.6 Gt materials that enters the global economy annually, 31.0 Gt is added to stock, while only 8.6 Gt is recycled. (CGRi 2020).

In a world where the global economy is expanding, recycling of additional resources will not be sufficient to gain sustainability (Grosse 2010), and it is important to stress that circular economy is more than recycling of materials. Circular economy is expected to not merely recycle materials, but also to reduce waste og improve resource productivity; thus, reducing environmental impacts from production and consumption. The International Resource Panel use the term *decoupling* as the necessary result of the circular economy: “The decoupling of natural resource use and environmental impacts from economic activity and human well-being is an essential element in the transition to a sustainable future” (IRP 2019:28).

20.3 Waste Policies and Regulations

Since the 1990s, the *waste hierarchy* as presented in Fig. 20.1 has provided a tool for developing waste policies and regulations. In Europe, the hierarchy has been implemented as a main part of the international waste legislation. Based on this waste hierarchy, several targets have been developed. An important target is that by 2035, 65% of all municipal waste should be re-used or recycled. Waste hierarchy provides a direction for the development of the circular economy. However, it is necessary to also include other elements from the CapSEM toolbox, such as design, labelling, supply chain management and monitoring. The ‘Circular Economy Package’, is an example of this (Stahel 2017).

20.4 Municipal Waste Management in the Ålesund Region

ÅRIM is a waste management company owned by seven municipalities in Norway. The company was established in 2010, and the main purpose of the company is to manage household waste from approximately 105,000 inhabitants. The collection system for household waste was originally based on a two-bin-system, with the collection of paper and plastic every month and collection of residual waste every week. Glass and metal packaging was not collected on a household level but had to

Fig. 20.1 Waste hierarchy

be transported to local recycling stations. ÅRIM carried out an analysis of waste production and composition from local households. The analysis was based on national waste regulations, and results from LCA and carbon footprint of products (CFP), for household waste in general (Raadal et al. 2009) and for food waste in particular (Modahl et al. 2016). ÅRIM on average (2017–2020) received 384 kg household waste per inhabitant per year, as shown in Table 20.1. In 2017, 32 % of the household waste managed by ÅRIM was re-used or recycled.

In 2018, the collection system for approximately 55 % of the households in the region was changed to a four-bin-system, with the collection of food waste and residual waste every second week. Paper and plastic are collected once a month, as before. In addition, glass and metal packaging is collected every second month. Food waste is used to produce biogas and fertilizer, paper, plastic, glass, and metal packaging are recycled while residual waste is incinerated, producing electricity and heat. The results of the change in collection system are shown in Table 20.2.

The change to the collection system has improved the sustainability of waste management from households in ÅRIM, as more waste is recycled and less is incinerated. In 2019, 45 % of the household waste managed by ÅRIM was re-used or recycled. From 2023, all households will have a four-bin collection system. However, further work is needed to identify any necessary circular strategies. This is a challenge for most Norwegian municipalities (Norwegian Environment Agency 2021). In its role as a waste management company ÅRIM is unlikely to achieve these goals on its own. A partnership between industry, waste management companies and regulatory authorities is necessary.

Table 20.1 Waste per inhabitant (measured in kg waste per inhabitant per year (average 2017–2020) (Annual reports published at *www.arim.no* and internal data)

Collected at household level (incl. glass and metal packaging)	230 kg
Brought to recycling stations (bulky and hazardous waste)	154 kg
Total waste production	384 kg

Table 20.2 Collected waste (Annual reports published at *www.arim.no* plus internal data)

Categories	Collected kg per inhabitant 2017	Collected kg per inhabitant 2019	Change kg per inhabitant
Food waste	0	35	**+ 36**
Paper waste	39	34	**- 5**
Plastic packaging	5	7	**+ 2**
Glass and metal packaging	10	14	**+ 4**
Residual waste	182	133	**- 49**
Total collected	**237**	**227**	**- 10**

20.5 Applying the CapSEM Model to Local Waste Management

The CapSEM Model is useful in many ways. For ÅRIM it can be used as a top-down framework for the waste collecting system ÅRIM is using, which is based upon international and national regulations. These regulations are based on the principles of sustainability and circular economy (change on the system level is defined as Level 4 in the CapSEM Model). The regulations are implemented through environmental management systems and reporting systems in ÅRIM (change on the organizational level is defined as Level 3), established for providing all interested parties (such as authorities, owners, customers, and neighbours) with necessary information. In order to achieve recycling targets, ÅRIM must inform consumers in the regions about how to recycle, and also about how to buy products that are more durable, can be repaired or recycled (change on the product level is defined as Level 2). Finally, ÅRIM also needs to implement measures on our own waste management facilities to comply with existing and new environmental legislation, preventing emissions to water, air and soil (change on the production level is defined as Level 1).

20.6 Concluding Remarks

The types of changes in global systems needed to reach UN Sustainability Development Goals requires a fundamental shift in the purpose of business and almost every aspect of how it is conducted. There is a need for innovation of more sustainable business models (Bocken et al. 2014). Sustainable business model innovation might be described as an important link between Level 3 and Level 4 in the CapSEM model. Business model innovation is necessary to achieve system change, but it also represents a threat to organisations which are unable to adapt. As the current use of resources is unsustainable, and as the current waste business models are insufficient for achieving a circular economy, the next decade is likely to experience a rapid innovation of new business models challenging the traditional waste management companies.

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Part IV
The Road Ahead

Chapter 21
Transition to Sustainability

Annik Magerholm Fet and Martina Keitsch

Abstract Companies are increasingly faced with the challenge of how to implement sustainability strategies in their business performances. This chapter discusses transition processes, presents mechanisms, and clarifies how tools and methodologies from Part II of this book can help companies in the transition process towards more sustainable practices. It further elaborates on how the CapSEM Model contributes to bottom-up approaches to sustainability transition processes as well as the importance of stakeholder collaboration and involvement.

21.1 Introduction

The different parts of this book have illustrated how the tools in the CapSEM Model can be used systematically to build knowledge and competence in sustainability towards more systemic and inclusive interactions. It is important to perceive the development of the model as a transitionary process where sustainability strategies become increasingly holistic and comprehensive, while the tools on each level build upon each other. Each wave movement between the levels, (Cf Fig. 2.1 in Chap. 2), symbolizes a growth of the number of sustainability impacts managed and stakeholders incorporated. The CapSEM Model provides thereby a common onset for several actors regarding their interplay and collaboration.

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21.2 The CapSEM Model as a Means for Transition

A transition to sustainability is defined as a "radical transformation towards a sustainable society, as a response to a number of persistent problems confronting contemporary modern societies" (Grin et al. 2010). Transitional change refers here not only to an understanding of how the tools presented in this book can help companies to move from a lower level to a higher level of maturity, but also how they can stimulate their efforts to develop own pathways that will enable a shift towards sustainability. Capacity building to achieve transition to sustainability thereby requires generating, structuring, storing, retrieving, communicating, and acting upon information and knowledge. Transitions are achieved through decisions to trigger small or large-scale change from one state to another.

The CapSEM Model represents the toolbox for transition to sustainability. Level 1 and 2 are analytical methods for quantification of environmental aspects and impacts, and tools for improvement as, for example, Cleaner Production on Level 1 or Supply Chain Management on Level 2, while Level 3 tools focus on how to achieve strategic changes through dialogues with stakeholders. Level 4 addresses larger systems as for example cities and their role to meet the needs of communities, providing leading visions and strategies in achieving sustainability in collaboration with stakeholders.

21.3 A Toolbox for Transition to Sustainability

Looking back to Part I of this book, Chap. 2 gives an overview of earlier models that have led up to the CapSEM Model as presented in Fig. 2.1. While Fig. 2.3 is an attempt to classify the set of principles for environmental performance improvement as appeared in the literature at that time, Fig. 2.4 shows adaptations from the first model, most notably the addition of specific tools and methods for life cycle-based environmental assessment management mapped along environmental performance improvement levels.

The CapSEM Model is designed to help companies understand their role and the relations of their actions within different levels of related systems. A systematic use of the tools helps companies investigate the potential for appropriate actions to change the environmental and sustainability performance related to each level (Fet et al. 2013, Fet & Knudson 2021).

The term *change* on each level in the CapSEM Model is used to mean the reduction of negative impacts and increase of, or replacement with, positive impacts—ultimately leading to strong, proactive, and holistic sustainability as companies move toward the upper right of the model. As an organisation traverses the levels, knowledge and tools from the previous levels are used as input to more extensive methods, meaning that each level encompasses the level(s) below it. These small stepwise changes have been important parts of the transition towards sustainability.

Over years these have led to incremental changes in business performances. An important question is however if these steps are sufficient to meet the global challenges the world is facing.

The UN General Assembly held an international meeting entitled "Stockholm+50: a healthy planet for the prosperity of all – our responsibility, our opportunity" in Stockholm, Sweden, from 2–3 June 2022 (United Nations, 2022). This was a conference reflecting back to the first UN conference on the human environment held in Stockholm in 1972 (United Nations 1973). The goal of Stockholm+50 contributes to accelerate the implementation action for meeting the 17 Sustainable Development Goals (SDGs) that define the future development agenda for 2015–2030. The aims of the SDGs advance the discussion on a better world, with emphasis on values for human rights, justice, health, and well-being. Ecological, social and economic developments are considered interrelated (Keitsch 2018). The following sections discuss how the CapSEM Model responds to the SDGS, as well as mechanisms and roadmap, and stakeholder collaboration to approach transitions to sustainability.

21.4 The CapSEM Model Meets the SDGs

The CapSEM Model with the SDGs integrated as presented in Chap. 3, Fig. 3.3, is a way of structuring the SDGs according to how they can be a pathway in the transition to sustainability at each of the 4 Levels. The additional value provided by the SDGs placement in the CapSEM Model is the toolbox to be used by companies and other organisations in this transition. The CapSEM Model helps make sense of the many methods available for tracking, measuring and improving sustainability performance by grouping them by level.

In business practice, cherry-picking of selected SDGs that neatly meet ongoing operations is common, as is ignoring interactions between them, or failing to reflect upon the system as a whole. A clear company strategy is needed in order to prioritize areas for sustainability improvement, related SDGs and targets. For that reason, the placement of the SDGs in the CapSEM Model represents suggestions for paving the way for business in identifying how their operations initially relate to each goal rather than absolute positions.

If companies better understand, and engage with the goals, their ability to prioritize and make strong measurable contributions to their targets increases. This includes minimizing resource use and avoiding pollution and the unnecessary expense and disposal of resources, especially into natural systems. Input-output (I/O)-analyses can be used to quantify material flows within a production process or a company's production site. Then, the quantified information can help inform decisions about the best solutions for designing new or adapting processes to reduce negative environmental impact, and meeting SDG targets, for example, for SDG number 6, Clean water and sanitation, the increase in efficiency of water use (target 6.4) and the protection and restoration of water-related ecosystems (target 6.6). The selected goals and targets for improving sustainability can be used to guide companies in selecting indicators and making strategic decisions on how to reach them using the tools and methods at this level.

Similar reflections can be carried out for SDG 13 Climate action, SDG 14, Life below water, and SDG 15, Life on land. It is worth mentioning that these SDGs, placed at Level 1 are highly relevant for all levels, but the impacts on these elements of the nature are caused by flows of material (natural resources) out of nature and likewise into nature as a result of system interactions between natural systems and technology, most often grouped as man-made systems.

Moving from Level 1 to Level 2 means that in addition to production processes, all other impacts related to a product and its value chain are considered, such as transportation of materials and components in the upstream life cycle of the product. In addition, downstream issues of distribution, maintenance and repair during the use phase and end of life treatment should be monitored for the entire life cycle of the product. Development shows an increased requirement for documentation of, for example, the carbon footprint of products. This means that the company should take responsibility for achieving quantified information from the suppliers of materials, components, and services across the life cycle. Based on quantified information, solutions for reducing GHG-emissions could be achieved through changes to renewable energy sources. SDGs 7 (clean energy) and 12 (responsible consumption and production) are therefore grouped on Level 2 to capture both upstream and downstream value chain sustainability improvements. SDG 12 places a focus on the entire value chain, and here SDG 7 requires that products are designed and manufactured for cleaner energy systems. Because Level 1 can be seen as an input, or subsystem, to Level 2, the goals and targets at Level 1 must necessarily also be accounted for.

SDG 8 (decent work & economic growth), SDG 9 (industry, innovation & infrastructure), and SDG 10 (reduced inequalities) are part of the economy as illustrated in Fig. 3.1 in Chap. 3 and are therefore placed on Level 3 in the SDG-CapSEM Model. Pressure from public procurement and customer demands for products that support more sustainable living or help clean-up past damage, encourage companies to report and communicate their progress toward improved sustainability. They must, therefore, develop their organizational strategies and practices (Level 3) in accordance with known guidelines and frameworks including SDGs. This requires information from the companies across all levels being dependable. For example, that all Level 1 processes are controlled and managed in a sustainable way, that systems for quantification of for example the carbon-footprints are in place at Level 2, and that the companies can present a certified environmental management system at Level 3, for example according to ISO 14001, that supports the company in their annual assessment of improvements. The tools presented for Level 3, as well as for Levels 1 and 2, should help the company to communicate the performance and give the stakeholders the information they need for an eventual approval of the sustainability performance or ranking of the company. SDG 10 is placed on Level 3 and relates to the social aspects of, for example, equal employment and income and stakeholder inclusion to be mandated within the company's sustainability management systems and strategic organizational goals. SDGs 8 and 9 have also been grouped on the organizational level. This is because they pertain to the economic viability of a company and may further support its knowledge and innovation development related to products that support a sustainable society.

Level 4 relates to tools, strategies and policies that drive systemic societal change and mandate the company view itself as one actor within a network of actors. SDGs 1 (no poverty), 2 (zero hunger), 3 (good health and well-being), 4 (quality education) and 5 (gender equality), are placed at this level as they represent the basic criteria for thriving livelihoods. Without meeting these livelihood goals, sustainability will not be reached or maintained over time. They also require that companies consider all stakeholders in their actions. SDGs 7 (affordable and cheap energy), 16 (peace, justice and strong institutions) and 17 (partnerships for goals) are also on Level 4 as they help companies recognize their place in the regional, national and global system. In a smart and sustainable city system, for example, there are increasing requirement to document the carbon footprint of subsystems, from furniture used in public spaces and private homes, to infrastructure that is designed for easier repair and supports smart renewable energy systems. The need for take-back systems and sharing economy systems will also appear more frequently, and industrial ecology (IE) is one of the tools for symbioses within a circular economy. Similarly, systems engineering is an important tool for seeing systems and their interactions from a holistic perspective. Level 4 embraces also the underlying features of Levels 1, 2 and 3.

21.5 Mechanisms and Roadmaps

Since the first world UN conference on sustainability took place in 1972, a plethora of models, guidelines, goals and scenarios have been produced. Some are referred to in this book to reflect on their effect on the transition to sustainability. Mechanisms and roadmaps such as the Taxonomy (Schütze, F & Stede, J, 2020), the Norwegian Transparency Act relating to enterprises' transparency and work on fundamental human rights and decent working conditions (Transparency Act, 2022) and the European Green Deal, the EU's guidelines for a sustainable economy (European commission, 2019), are important to facilitate sustainable transitions. In addition, there is an increased focus on ESG-reporting since the financial sector has become more active in requiring business to hold and report this type of information. The EU Taxonomy, the Transparency Act and ESG-reporting scheme are presented in Chap. 7.

The European Green Deal contains several opportunities for moving towards sustainable business performances such as innovation-based competitiveness. This concerns the potential for low-emission technologies, and sustainable products and services. Business leaders tend to take the European Green Deal on board as a growth strategy. However, systemic transformation delivers the highest growth in medium to long-term run, and short-term benefits are questionable. Further, authors such as Pianta et al. (2020) criticize among others the EU's weak policy tools for initiating change in business:

> Business has no clear set of incentives for investing in sustainable production, and Member States have no official political constraints that may push governments to implement a Green Deal agenda. (Ibid, 635)

According to Stockolm+50 a common political and business focus on qualitative growth can become an important driver to initiate transition to sustainability. Future industry might not be able to expand by manufacturing more products but by innovation and development of products and service of higher quality. Creative efforts of businesses and governments both contribute to qualitative growth.

The main goals of the European Green Deal are:

EU to become climate neutral by 2050

1. Protect humans, animals, and plants by cutting pollution
2. Help companies become world leaders in clean products and technologies
3. Ensure a just and inclusive transition.

The way in which the Green Deal can be understood as an opportunity for business management as a combination of sustainability motivation and regulation is discussed in the Green Deal Roadmap (European Commission 2019). Its main ambitions are energy security, climate neutrality, resource efficiency and circularity, smart mobility and toxic-free environment are among the areas which are focused on. In addition, the use of regulation and standardisation, investment and innovation, national reforms, dialogue with social partners and international cooperation will be strengthened (European Commission 2019).

21.6 Stakeholder Collaboration

Sustainable Development Goals define a future development agenda to encourage the international community to move toward a global sustainable future in the next few decades. Against this backdrop, the implementation of the SDGs raises questions regarding human–nature relationships in terms of sustainable resource use within the limits of ecosystems, but also in terms of just distribution, fair societies, and equal opportunities. Realising the SDGs in both broad arenas, resource consumption and nature conservation, and inclusion and justice, societal stakeholder collaboration is crucial. This means involving, among others, societal actors such as academics, business and political decision-makers on all levels in the planning and development of SDG strategies. The learning outcome of stakeholder collaboration should not be underestimated (Kerkhof et al. 2005).

The CapSEM Model facilitates stakeholder collaboration through the tools that support the design and uptake of sustainable approaches for local, regional, and global sustainable development. Although tools are more selective on Level 1 and based mainly on organisations making improvements which benefit themselves, rather than the greater good, stakeholder involvement is required for companies to make sustainability improvements at all other levels.

Level 2 improvements rely, for example, on existing knowledge and common knowledge generation from various actors on the materials of a product, associated costs, maintenance practices, transportation and marketing, to name but a few, since stakeholder collaboration takes place in many parts of the products' and company's value chains.

Level 3 requires communication with stakeholders to best define reporting, measuring and management plans for improved sustainability. For example, in establishing strategy benchmarks, a company will need to select environmental and social performance indicators in collaboration with stakeholders to measure their progress. In this case, the collaboration comprises employees, consumers, local community members, marketing firms and company management.

At Level 4, stakeholders are extensively involved as part of an overall systems change on the macro level, with their input providing necessary information for all tools at this level.

The following chapters illustrate how different stakeholders benefit from the model and pinpoints strategies for further development. Chap. 22 has a focus on business model innovation for sustainability (BMIfS) as a means for enhancing the transition on the strategic organisation level, while Chap. 23 looks at decision support systems for Level 4 of the CapSEM Model, i.e., system change, which is a complex undertaking due to the high number of stakeholders involved.

21.7 Conclusion

This chapter discussed approaches and mechanisms that stimulate processes for transitions to sustainability in business and other organisations and connects them with the CapSEM Model. Tools for analysing the environmental aspects and impacts are placed on Levels 1 and 2 in the model. Decisions about the systems to be studied and the elements of sustainability to be covered by the analyses, are taken at an organisational level, Level 3, and at a societal level, Level 4. This can be viewed as a bottom-up approach in the process of a transition to sustainability. Competence among business leaders and politicians and their ability to take a holistic systems perspective are therefore of paramount importance in achieving such transitions.

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Chapter 22
Helping Business Contribute to a Sustainability Transition: Archetypes of Business Models for Sustainability

Haley Knudson and Martina Keitsch

Abstract This chapter discusses business models for sustainability (BMfS). The objective for BMfS is to increase positive or decrease negative impacts of business performance on the environment and society, simultaneously providing long-term well-being of the organization and its stakeholders. The chapter looks at BMfS from a systems perspective and analyses how sustainable values are integrated into organizations' performances. Furthermore, benefits and challenges of BMfS related to capacity building, stakeholder inclusion and the scope of innovations inherent in the models are discussed. Conclusively, the chapter appraises the potential of BMfS to contribute to macro level transition to sustainability.

22.1 Introduction

Business models for sustainability (BMfS) continue to gain attention, both in academic research and in practice as a means to achieve sustainability innovation and restructuring in organizations. Business model innovation for sustainability (BMIfS) is the process of increasing positive or decreasing negative impacts on the environment and society that also allows the long-term well-being of the organization and its stakeholders (Geissdoerfer et al. 2018). The complex process requires that an organization situate itself within its network of actors to see how sustainability-focused innovations will permeate its business model (BM) activities and effects on wider society.

BMfS archetypes are introduced in Part II Chap. 9. These are common patterns of BMfS that have been categorized according to their type of sustainability innovation (Bocken et al. 2014). Based on the archetypes' guidance, organizations can identify types of innovative and strategic activities that can help infuse an existing

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BM with sustainability or create a completely new model with sustainability as the core logic. The archetypes provide inspiration to organizations by demonstrating how BMfS differ from traditional BMs and innovations that have worked for others. However, the focus on one innovation mechanism or type within each archetype may encourage a limited view to sustainability innovation in BMs, which in turn may influence the sustainability perception and performance in the organization. Taking only the archetypes perspective may also hinder the full integration of sustainability into an organization's value proposition, value creation and delivery, and value capture activities – preventing the creation of a business model that helps mediate environmental and social needs. On the other hand, more holistic archetype implementation, i.e., models which provide ways to infuse stakeholder needs and environmental objectives through the whole business model, can enhance organizations' sustainability performances significantly on a systems level.

The transition to sustainability and meeting the objectives set by the UN Sustainable Development Goals (SDGs) (United Nations General Assembly 2015) requires a holistic and transdisciplinary approach that is rooted strategically in an organization and therefore demands broader thinking than the identification and implementation of a single potential archetype. Organizations must consider their full value chain performance, including their network of stakeholders, to build and positively impact social and environmental sustainability in the long-term. Such requires the redefinition of value within the organization to include both financial and non-financial (social and environmental) value forms, and their exchange and capture within the business model (Evans et al. 2017). More holistic archetypes may therefore be identified in the future, that influence and direct the organization's sustainability awareness and performance towards the wider system of which it is part.

The next sections of this chapter discuss BMfS archetypes in relation to the following topics:

(a) The process of BMIfS and the integration of sustainable value into systemic organization performance,
(b) benefits and challenges for capacity building in organizations' sustainability and environmental management portfolios,
(c) the inclusion of stakeholders in existing and future BMfS design and realization, and
(d) the scopes of innovation embedded in the archetypes and their impact on changing societal systems.

Conclusively, their potential to contribute to developing changes and innovations at the organizational level that contribute to system-level sustainability transition is appraised.

22.2 Business Models for Sustainability

Innovation, knowledge building and strategic change for sustainability are dependent on a shift in the rationales and values that drive an organization (Laasch 2018, 2019). This requires, among others, a turn from creating value for customers and shareholders, to creating, or at least not destroying, value for all stakeholders, including the environment and society as key players (Boons and Lüdeke-Freund 2013; Bocken et al. 2014). Stakeholders are here understood as individuals and groups, who have an interest in the situation and its development or could potentially be affected by it.

Traditional BMs have been based on a shareholder primacy perspective, selling goods and services to customers with the lowest cost to the organization to ensure the highest financial return and value added for its shareholders. A *BMfS*, on the other hand, creates value beyond the organization and its shareholders to actively integrate the needs of stakeholders into what it delivers to the customer (value proposition) along with its upstream and downstream activities and resources (value creation and delivery). Additionally, a BMfS bases itself in the exchange of social, environmental and economic value with its stakeholders and value chain actors (value capture), rather than in only financial flows of costs and benefits.

The term 'value' and its variants comprise multifocal interpretations and have has been extensively discussed in management sciences. A general definition of 'value added' is: "the difference between the value of a firm's output and the cost of the firm's inputs" and it is seen as "the key measure of corporate success" (Kay 1995) (p. 19). Value creation depends on the relative amount of value that is subjectively realized by an individual, an organization, or a society connected to the willingness to exchange a monetary amount for the value received. Moreover, a more recent 'value-creation' variant focuses, supplementary to the monetary value, on the resource-creation potential of firms considering, knowledge, innovation, social networks, and sustainable growth (Lepak et al. 2007).

BMfS are rooted in *sustainable value* that "incorporates economic, environmental and social benefits conceptualized as value forms" (Evans et al. 2017 p. 601). These value forms should then be considered within and across the BM components of value proposition, value creation and delivery, and value capture. Figure 22.1 provides examples of economic, environmental, and social value forms that contribute to sustainable value creation.

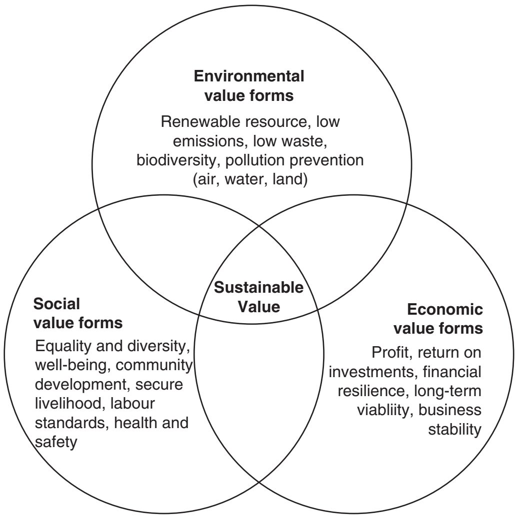

Fig. 22.1 Sustainable value. (Evans et al. 2017)

22.2.1 Business Model Innovation for Sustainability

Innovation is a process of creating new value. Because sustainability objectives require departure from the traditional logic of purely profit-making BMs, the development, adaptation and advancement of BMfS should be approached as an innovative process. Disruptive innovation is specifically interesting to develop BMfS since it transforms businesses on a systems level by, for example, making BMfS applicable for a broader range of companies, and obsoleteing more traditional competitors. Traditional business model innovation (BMI) literature, focuses on the process of the successful commercialization of new technologies or ideas through an organization's BM (Chesbrough 2007). BMIfS extends this by adding or adapting aspects, technologies and mechanisms that reduce negative and increase positive sustainability impacts in the organization's BM, and that support the long-term viability of the organization and its network of stakeholders (Boons and Lüdeke-Freund 2013; Geissdoerfer et al. 2018; Sinkovics et al. 2021).

Research on sustainability-oriented innovation has addressed several individual elements, for example, how to make supply chains more sustainable or how to use corporate responsibility activities to create value for employees and their families. Each of these technological or social innovations contribute to making the BM one that supports sustainability, but BMfS also require that the BM itself is reconceptualized to create and capture sustainable value within its wide stakeholder network (Stubbs and Cocklin 2008; Evans et al. 2017). BMIfS therefore requires changing how is business is done so that strategic aims for sustainability infiltrate the BM and its activities (Schaltegger et al. 2012a). Based on their sustainability strategy, an organization may choose to take a *defensive*, *accommodative* or *proactive* approach to innovating its BM (Schaltegger et al. 2016). These range, respectively, from making small incremental changes to mitigate risk and reduce cost, to improving internal processes that consider sustainability on some level, to the redesign of the core logic of the business for sustainable value (Schaltegger et al. 2016). It is the proactive approach that helps organizations initiate and guide a wider sustainability transition, while accommodative and defensive approaches are typically in response to top-down sustainability mandates or policies on the corporate, governmental, or societal levels. A BM with sustainability at its core requires that the business model itself is reconceptualized to create and capture sustainable value within its wide stakeholder network (Stubbs and Cocklin 2008; Evans et al. 2017).

A holistic approach that considers sustainability across the BM, and that is representative of the system of interactions between BM components and stakeholders is therefore needed (Boons and Lüdeke-Freund 2013; Abdelkafi and Täuscher 2016; Proka et al. 2018). This requires recognition of the interdependencies between an organization, its business model, its partners and surroundings, and expands the scope from small incremental modifications, to innovative change with environmental and social needs at the center (Wells 2013). BMs are the mediating layer between operational activities and organizational strategy (Osterwalder 2004; Rauter et al. 2017), and BMI processes therefore serve as a link between the internal

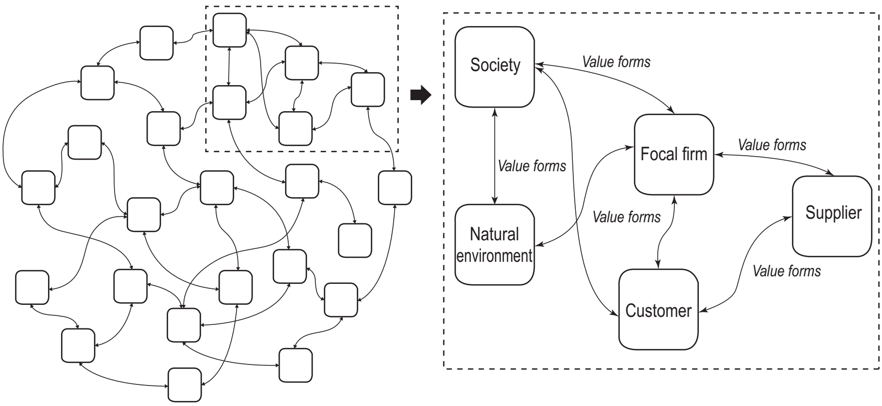

Fig. 22.2 Sustainable value network. (Evans et al. 2017)

and external business environment, strategic aims, and their operationalization in the BM structures and activities. When markets, regulations or stakeholder expectations change, the organization can then assess the system of activities that make up its value network (Zott and Amit 2010) to identify how to innovate within the BMfS in line with its strategic aims and performance objectives. Figure 22.2 provides a representation of an organization's value network in which the relationships between the focal organization and its stakeholders are shown as value forms (exhibited in Fig. 22.1). For example, relationships with societal stakeholders may bring.

The shift in ideology of the current market, from profit as the only value, to the incorporation of environmental and social value, requires, in itself, a different way of thinking that transforms the way organizations and society place value on consumption and short-term thinking. By innovating and re-designing their BMfS, organizations can contribute to environmental and social sustainability and facilitate attitude change of their consumers and stakeholders to shift demand toward sustainability. On a macro level, disruptive innovation in BMfS design is a key factor to promote, for example, a circular economy through transformation of the linear market (Diepenmaat et al. 2020).

BMI for sustainability requires the simultaneous consideration of the business model and its value network, the three dimensions of sustainable value, active engagement with stakeholders and the long-term perspective, all while organizations have to manage day-to-day operations and viability (Stubbs and Cocklin 2008). Although complex, by situating its BM within the value network, an organization can use it as a mediator between institutional and societal influences and sustainability innovation within its boundaries (Lüdeke-Freund et al. 2018; Lüdeke-Freund 2020). This enables the organization to react to external influences, such as new initiatives or regulations, and to support and incorporate stakeholder needs. The BMfS is then a framework through which organizational boundaries must expand to expose interactions with social and environmental actors in the business and institutional contexts (Boons and Lüdeke-Freund 2013; Brehmer et al. 2018).

22.2.2 Barriers to BMI for Sustainability

Business model research, and by extension BMfS research, has been conducted from multiple perspectives spanning from classification and architectures to operational and strategic mechanisms, taking both static and innovative process development approaches (Morris et al. 2005; Demil and Lecocq 2010; Foss and Saebi 2017; Ritter and Lettl 2018; Geissdoerfer et al. 2018) into account. To apply the concept of BMfS on strategic and organizational levels, it is important to move from seeing it only as an outline or architecture of the status quo, to acknowledge it as a system of interacting activities with may initiate change and contribute to innovation.

A challenging aspect of pursuing the research or implementation of a BMfS is linking the concept to practical execution by identifying feasible and appropriate opportunities and providing accessible tools. Barriers to BMI often arise because of a disconnect between the current functioning of the organization and the implementation and follow-up of new changes (Chesbrough 2010). Further, when adding sustainability considerations into the BMI process, the hurdles may be amplified. The multidimensional aspects of sustainable development can be difficult to balance and decision making between continuing opposing activities that support the financial viability of an organization yet do not support its sustainability objectives is difficult. While increasing the performance of its environmental management and sustainability portfolio can lead to the competitive advantage of a company (Kramer and Porter 2011; Schaltegger et al. 2012b), financial and human resource investments and restructuring may be required up front. When evolving the BMfS, i.e., the structures and mechanisms that allow an organization to create and capture sustainable value, the expanse of sustainability aspects and consideration of their interactions must be evaluated and monitored even more closely.

Even when an organization attempts to innovate its BMfS, successful implementation may not take place. Due to challenges related to, for example, balancing tensions between environmental, economic, and social objectives, redefining organizational logics and established norms, redistributing resources to build sustainability capacity, and establishing systems for engaging with stakeholders, a *design-implementation gap* has been identified (Evans et al. 2017; Geissdoerfer et al. 2018). Tools to assist organizations in the ideation and implementation processes of BMI for sustainability are therefore fundamental to their progress.

22.2.2.1 BMfS Archetypes as a Tool for BMI

Many tools have been developed to aid in the BMIfS process. One tool is *BMfS archetypes,* initially outlined by Bocken and colleagues in 2014 to help unify and interpret the exploding and fragmented literature on BMfS (Bocken et al. 2014). The archetypes are presented conceptually, and with reference to examples from business practice in the following sections.

The archetypes provide common models, patterns, or forms of BMfS that have been employed by other organizations. Their categorization helps to classify current knowledge on the subject and develop reference points for future research and application (Lüdeke-Freund et al. 2018). Such classification is important because the "ordering of objects into classes provides meaning to reality" and therefore helps to clarify the research area (Lambert 2015, p. 50).

Archetypes are also used as a tools for practitioners to begin thinking about how they may innovate their BMfS (Lüdeke-Freund et al. 2016; Jonker and Faber 2021). The simplicity of the archetypes allows organizations to focus on specific innovation mechanisms that they know other companies have already tested and applied, and therefore can serve as a low barrier entry point to the beginning of their innovation journey. When faced with pressure from customers, financing or regulatory bodies, organizations often want to look externally to what has worked for others as timely inspiration to their BMI process. They may therefore look to the recurring patterns of BMfS that have been successfully employed in other organizations. In the initial categorization of BMfS archetypes (Bocken et al. 2014), the models are grouped by their main innovation area – technological, social or organizational (Boons and Lüdeke-Freund 2013), and are discussed in terms of the way they seek to propose, create and capture ecological and social value. This grouping was later shifted to headings of environmental, social and economical categories (Bocken et al. 2016; Ritala et al. 2018). A ninth archetype was also added. The adapted grouping is intended to help clarify the sustainability dimension in which the new kind of sustainability innovation is occurring. Table 22.1 presents the nine archetypes along with examples and references for further reading.[1]

In terms of environmental innovation, the more technical archetypes of "maximize material and energy efficiency," "create value from waste," and "substitute with renewables and natural processes" suggest changes to the production processes, design or material selection within an organization's BM to reduce environmental impact in upstream value chain processes. In relation to the Levels of the CapSEM Model, the environmental archetypes can be considered to be representative of sustainable innovations on Levels 1 (production process-related) and 2 (product-related). Most display a closed systems perspective that sees the organization as a unit that interacts with the environment through e.g., 'pull and push' of markets. These archetypes, if not combined with wider BM changes, will lead to incremental changes and innovations, and less mature BMI for sustainability. Some advanced examples of the "create value from waste" archetype may contribute to

[1] It should be noted that these are not the only archetypes for BMfS. Another categorization of BMfS groups 45 sustainable business model patterns across 11 pattern groups based on their main value creation area (mainly economic, social-economic, social, mainly ecological, integrative) (Lüdeke-Freund et al. 2018). This taxonomy follows a more empirical and transparent methodology and was developed in response to the 'ad hoc' nature of the archetypes presented in (Bocken et al. 2014). Focusing on how and what kind of sustainable value is created may be a better way to group types of BMfS, however the taxonomy (Lüdeke-Freund et al. 2018) has not become nearly as mainstream as the archetypes (Bocken et al. 2014).

Table 22.1 BMfS archetypes

Grouping	Archetype	Examples
Environmental (Technological innovation)	**Maximize material and energy efficiency**	Low carbon manufacturing/solutions
		Lean manufacturing
		De-materialization; Digitalization
		Increased functionality; Lifespan extension
	Create value from waste	Closed loop/Cradle to Cradle
		Industrial symbioses
		Remanufacture; Take back management
	Substitute with renewables and natural processes	Renewable energy sources and innovations
		Zero emissions initiatives
		Slow manufacturing
Social (Social innovation)	**Deliver functionality rather than ownership**	Product-oriented (maintenance, extended warranty)
		Use-oriented (Renting, leasing, sharing)
		Result-oriented (Pay per use)
	Adopt a stewardship role	Biodiversity protection
		Consumer care – promoting consumer health and well-being
		Ethical trade (Fair Trade)
		Radical transparency
	Encourage sufficiency	Consumer education/communication
		Demand management
		Product longevity
		Premium branding/limited availability
Economical (Organizational innovation)	**Repurpose for society/ environment**	Not for profit
		Hybrid businesses, social enterprises (for profit)
		Alternative ownership: cooperatives, collectives
		Benefit corporations (B-corps)
		Social and biodiversity regeneration initiatives
	Inclusive value creation	Collaborative approaches (sourcing, production, lobbying)
		Peer-to-peer sharing
		Inclusive innovation; Base of the pyramid solutions
	Develop scale-up solutions	Open innovation
		Incubators and entrepreneur support
		Impact investing
		Crowd funding; Peer-to-peer lending

Modified from Bocken et al. (2016, 2019), Ritala et al. (2018)

the larger transition to a circular economy. However, since many of the existing examples suggest closed loops within a specific company or industry sector, rather than the economy at large, they are generally grouped in this analysis on the earlier Levels of the CapSEM Model.

Moving beyond environmental performance, socially innovative archetypes can be aligned with perspectives from Levels 3 and 4 of the CapSEM Model. These archetypes specifically include the consideration of stakeholder needs and larger initiatives that support sustainable development objectives and are therefore related to the higher Levels of the CapSEM Model that move beyond environmental performance to adapt BM structures in line with strategic sustainability approaches. Socially innovative archetypes focus on innovations that shift existing production and consumption patterns such as "delivering functionality rather than ownership", "establishing product sharing systems", and "adopting a stewardship role", for example by requiring suppliers to meet standards for ethics or biodiversity protection. On both the consumer and producer side, socially innovative archetypes include "encouraging sufficiency," among others, through designing products with longevity in the use phase to decrease the tendency to buy new products frequently. These archetypes progressively follow up the technological innovation archetypes that adhere to an 'accommodative' approach to organizational sustainability (Schaltegger et al. 2012b), that is, to reduce environmental impacts, and resist developing novel standards for decision-making in business. Other examples include circular economy based models that support changing production and consumption patterns, e.g., sharing platforms, product as a service, resource recovery and circular supplies (Moreno et al. 2016), and product-service system (PSS) models. These differ from the technical "create value from waste" BMs as they do more than change material, energy, and waste streams in production processes, and enable and depend on changes in upstream and downstream networks, and in producer and consumer conceptualizations of need and responsibility.

The economical archetypes demonstrate patterns of organizational innovation and can be situated on Levels 3 and 4 of the CapSEM Model. While it may seem counter-intuitive that the economic archetypes are at the higher Levels, this is due to their reconceptualization of the typical for-profit business model, that is, they make changes to the current economy in support of market and societal transition. They attempt to integrate societal norms and ethical thinking and decision-making into sustainable business strategies and solutions. Focusing on "repurposing the business for society/the environment," "inclusive value creation," and "developing scale-up solutions" supports the kind of disruptive business models needed for sustainable transition away from incumbent models (Christensen et al. 2006; Kivimaa et al. 2021). Logically, this surpasses the technological innovation archetypes by acknowledging that it is not possible to derive values for society from natural systems (Keitsch 2020a). Pragmatically, this means there is a need to relate to larger initiatives that support sustainable development objectives and to include societal stakeholders' needs, values, and norms in order to generate sustainable network impact.

Although the nine archetypes are separated and referred to individually, they must be combined to move to more holistic BMIfS that penetrates through the full business model (Bocken et al. 2014). For example, in the case of a product sharing platform BMfS (i.e., deliver functionality rather than ownership), material and energy efficiency measures of the technical archetypes must also be part of the BM to prevent unnecessary production of exorbitant products, or risk little reduction of environmental impact. Such parallels the logic of the CapSEM Model, as the tools and methods on the higher levels require application of the tools and perspectives of the lower levels.

22.3 Discussion

The categorization of archetypes above illustrates the possibilities for implementation of BMIfS processes into the business models of real-world organizations. Using archetypes as a representation of the potential for sustainable innovation within BMs can provide organizations examples of experience and techniques from practice and help reduce the risk associated with restructuring a BM (Bocken et al. 2014). The reduced risk can help encourage organizations to attempt their own incorporation of sustainable value, through the selection and combination of different archetype principles appropriate for the particular business. The archetypal innovation strategies and mechanisms can then be considered in relation to an organization's specific value chain processes and existing business model. They can also be combined in configurations that best support the organization's sustainability strategy and stakeholder needs. When applied in practice, BMfS archetypes can be used by organizations among others as a quick fix to meet sustainability demands, without considering all aspects of sustainability and the societal and environmental impacts on a holistic scale. Some authors claim that, trapping ideas from established models may yet limit the impact of BMI outside of the organization (Morris et al. 2005; Chesbrough 2010; Demil and Lecocq 2010; Boons and Lüdeke-Freund 2013), which will be further discussed in the following.

Improving sustainability performance and innovating BMs for sustainability helps organizations support and incorporate macro-level sustainability objectives into their activities. To design, implement, or transit to a BMfS, organizations must implement activities that make their business model one that promotes sustainable innovation and that contributes to sustainable development in the larger system of which it is part (Diepenmaat et al. 2020), not only in the organizational unit. While archetypes may help direct the identification of sustainable innovation opportunities, they may also lead to ignorance of the entire set of activities and interactions that make up the organization's BM. It is therefore required that the organization also views its BM as a system of activities (Zott and Amit 2010; Evans et al. 2017), with interdependencies between activities, to create a comprehensive picture of how it operates within its multilevel context. Incremental choices that impact one activity and the achievement of its purpose may positively or negatively affect other activities, therefore impacting or changing the accomplishment of the overall objective of the value proposition for the customer and stakeholders.

From a systems perspective, socially innovative archetypes are the most advanced systems. They represent BMfS that are 'autopoetic,' i.e. that perceive business as an 'ecosystem', embedded in a network of other entities, or 'subsystems'. Their rationale is that business evolves and thrives not just together with other businesses but also through interdependencies and in interaction with various subsystems (Valentinov 2014). Moving towards CapSEM Model Level 4, the socially innovative archetypes expand the structure of business interactions, and design new types of exchanges among organizations and societal stakeholders. Moving to an autopoetic systems literacy allows sectors and industries to realize the interconnected structure of organizations, technologies, consumers and products (Kohtamäki et al. 2006; Keitsch 2012).

In terms of sustainability performance, businesses oriented toward organizational innovation may commonly develop incentives and a vision to strive for sustainability goals, develop individual initiatives while using political mechanisms to ensure that their activities will reach these goals, and coordinate the internal with the external pace of innovation (Anggraeni et al. 2007). The economical archetypes, then, can support the complete reformation of traditional make-and-sell BMs through organizational level innovation. For example, to 'repurpose the organization for the society and/or environment,' as, e.g., not for profit organizations or social enterprises, or to 'develop scale-up solutions' to sustainability that reduce competition and increase collaboration among organizations in support of open innovation initiatives, industrial cluster formation or crowd-sourced models. Economical archetypes focused on organizational innovation allow actors to revise their value orientations and innovate their business models as results of novel activities, roles and structures. The societal context of businesses is even more emphasized in organizational innovation archetypes and the mutal influence of business and societal stakeholders is explained in close context to socio-cultural innovation via new partnerships, business-citizen initiatives such as Open innovation platforms and transdisciplinary collaboration (Keitsch 2020b). These archetypes put stakeholder collaboration in the forefront in co-developing sustainability knowledge and -implementation strategies. The aim is to achieve 'sustainable well-being' of all societal stakeholders by aligning business strategies and solutions to ethical principles defined by social systems, institutions, and environments. The 'common good' of sustainable well-being is heuristic, it assumes that even if assumptions, expectations, attitudes, values, and interests that influence decisions vary greatly in societies, consent is possible.

The *repurpose for society and the environment*, and the *development of scale up solutions* in the table above illustrate the aim of sustainable well-being as one onset for the organizational innovation archetypes. In terms of disruptive innovation, these archetypes can complement policy and social groups efforts to support the transformation necessary to achieve sustainable societies. For example, the scale up solutions might bring major benefits for society by including larger populations, and new groups in the development process. As Iizuka and colleagues (2021: 16) point out: 'Disruptive inclusive innovation (DII) " …. can be initiated by the private sector without much government involvement. Entrepreneurs respond to the unmet demands of citizens by devising an innovative business model, linking the underserved population with new services using emerging technologies to generate broader impacts".

22.4 Conclusion

Implementing and examining the full portfolio of sustainability needs and requirements that result from the activities within the business model can help an organization change or adapt its BMfS to create more disruptive and inclusive social and environmental impact. While archetypes are useful for ideation and experimentation, it is essential that they are inserted into the understanding of the business model as a whole. This entails considering innovation archetypes within the network of activities and actors that make up the current BM, identifying the expected impacts on stakeholders, and determining the contribution to the organization's sustainability performance (i.e. 'autopoetically'). This is supported by the definition of BMIfS provided by Bocken et al. (2014) in their archetype work: "Innovations that create significant positive and/or significantly reduced negative impacts for the environment and/or society, through changes in the way the organisation and its value-network create, deliver value and capture value (i.e. create economic value) or change their value propositions" (p. 44). However, consideration and integration into the wider value network of stakeholders is often hindered due to, for example, the challenges of the 'design-implementation gap' between ideation and implementation of BMfS (Geissdoerfer et al. 2018), the fundamental shift of core business logics from profit-making to sustainability creating (Laasch 2018) or a limited understanding of the dynamics of the process of BMIfS (Lüdeke-Freund 2020).

The question remains, if moving towards BMfS with the help of the archetypes will apply to every organization in a shifting market. Especially small and medium sized organizations that are not able to integrate insights from subsequent research and experience and may end up using tools that do not benefit their context, reducing their chances of success. For this reason, structural support in the form of, for example, transdisciplinary stakeholder collaboration, is essential to mitigate failures and achieve systemic macro level sustainability, a view that will be further elaborated in the next chapter.

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Chapter 23
Building Decision Support Systems for Sustainable Transitions

Dina Margrethe Aspen and Christina Carrozzo Hellevik

Abstract Developing decision support systems for sustainable transitions at the societal level is a complex undertaking due to the high number of stakeholders involved, the urgency of problems that needs to be addressed, and the uncertainty of information linked to decisions. A mismatch between the technological tools offered for decision support and the real needs of practitioners and society at large has been observed. In order to address these challenges, several approaches are explored under the theoretical framework of post-normal science, including co-creative developmental design, soft systems thinking and models for technology integration.

23.1 Introduction

Capacity building for environmental and sustainability management (CapSEM) to achieve sustainable transitions requires generating, structuring, storing, retrieving, communicating, and acting upon information and knowledge. Transitions are achieved through decisions, individual or in series, as instances or processes, made based on relevant information and knowledge, to trigger small or large-scale change from one state to another. Decision support systems (DSSs) help facilitate these transitions by offering actionable information to decision-makers and other stakeholders. DSSs may be defined as interactive computer-based systems that aid decision-makers utilize data and models to solve problems (Sprague Jr, 1980). Since the 1960s, these systems have evolved in scope and complexity to help address tasks at multiple organizational levels across several sectors. As the toolbox for sustainability transitions has grown, so has associated DSSs. While there exist several DSSs to address challenges at the process, product and organisational level, few DSSs currently are currently in use to support broader system change.

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In this chapter, the basic structures and features of DSSs are introduced and explored in the context of the CapSEM framework. The chapter discusses problem complexity as a barrier to developing DSSs for system change and explores pathways for creating DSSs for sustainable transitions at systems level. The case of Planning-Support Systems, i.e. DSSs for urban development and planning, is discussed drawing on experience from development projects in Norway.

23.2 Decision Support Systems for Sustainable Transitions

23.2.1 Structure and Components of Decision Support Systems

Arnott and Pervan (2005) define Decision Support Systems (DSSs) as "… the area of the information systems discipline that is focused on supporting and improving managerial decision-making". The concept emerged during the 1950s and 1960s when organizations started automating business operations such as order processing, billing, and inventory control using computers (Arnott and Pervan, 2005). Early DSS developers aimed to provide an environment where the decision-maker and the information system worked interactively to solve problems. Humans would deal with the complex and unstructured parts of the problem, while the information system would assist by automating the structured elements of the decision context (Arnott and Pervan 2005). Since their advent in the 1950s, DSSs have become prolific in several fields, such as business, agriculture, and clinical decision-making.

While several types of DSSs and problem domain applications exist, they all have in common some basic components. Figure 23.1 shows a generic structure of a DSS (based on Sprague Jr 1980). DSS users initiate computational procedures in the DSS through their queries and commands via the interface. Users may be decision-makers, i.e., the individual or group that faces the problem or decision and needs to act and hold responsibility for the consequences. Users may also involve intermediaries or other actors that have access to the system via their stakeholder role.

The interface offers functionalities tailored to the DSS with parameters the users may specify for the query or command. The interface displays query outputs, which may be unprocessed data or information derived from the model base. In some decision support systems, users may also enter commands (decisions) based on this information to record or activate a change in another system controlled by the DSS.

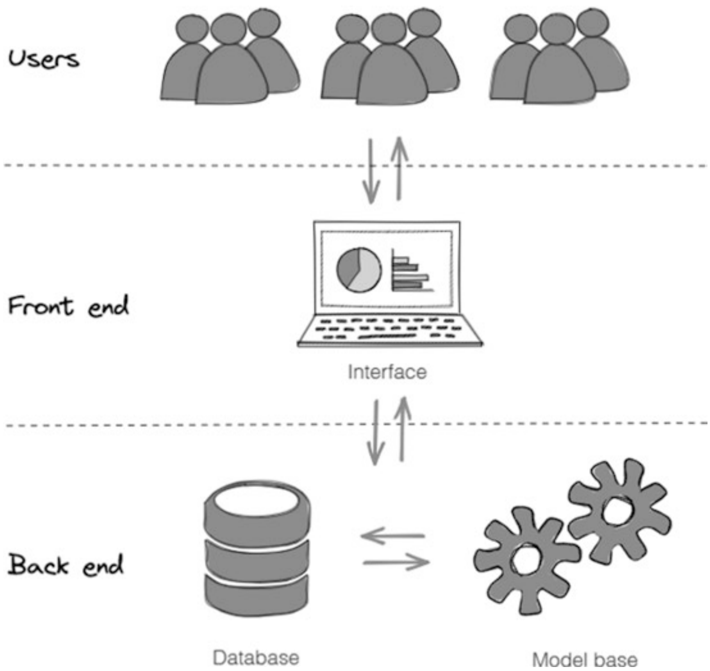

Fig. 23.1 Basic components of decision support systems (DSSs). (Modified from Sprague Jr 1980)

23.2.2 Decision Support Systems for Supporting Transitions to Sustainability

While DSSs have been prolific in nearly all industries and domains, systems dedicated to supporting sustainability have become more popular during the last few decades. Following the four Levels of the CapSEM Model, as shown in Fig. 23.2, DSSs that support decision-makers at each level currently exist.

For Level 1, multiple process optimization systems exist, such as e.g., marine fuel optimization to reduce fuel costs and emissions or maintenance optimization models to determine efficient intervals for machinery maintenance. These may be expert systems that are either integrated with wider enterprise management software or stand-alone applications.

For Level 2, a range of decision support systems also exists, such as e.g., life cycle assessment software to help decision-makers identify environmental hotspots and improvement potential across a product life cycle. SimaPro, GaBi, and OpenLCA are examples of tools that permit life cycle inventory modeling, environmental impact assessment, and sensitivity analyses. These tools may also contain features such as environmental product declaration generators or enterprise reporting functions to link product information to the wider organizational reporting.

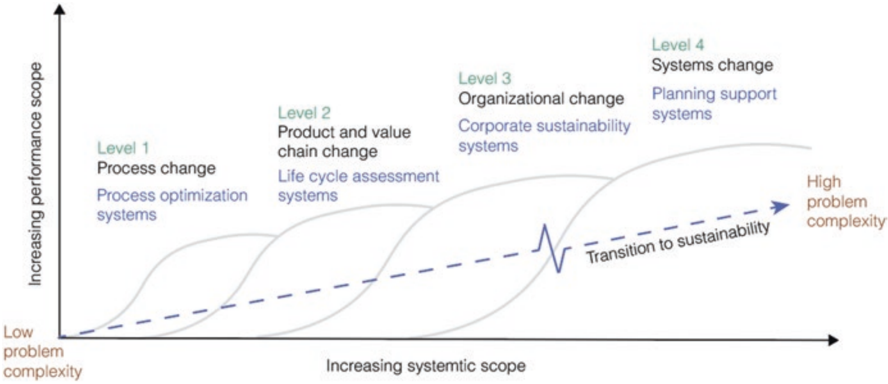

Fig. 23.2 Example of DSSs at various CapSEM levels

For Level 3, there are also numerous corporate sustainability systems for management, reporting, and communication. These range from simple dashboards that keep track of company performance across selected sustainability performance indicators to more advanced systems for managing sustainability performance, such as SoFi.

The types of problems exemplified above, all have a relatively simple, objective answer, which, assuming that the user makes the rational choice according to the priorities of the company, can truly optimize operations. However, moving from the organisational to the systems or societal level (level 4) in the CapSEM framework entails a great increase in complexity from a decision analytical viewpoint (Fig. 23.2). System change requires planning and policy-making at higher organizational levels, involving decision-makers from industry, government, and the wider public sphere.

An example of an attempt to build DSSs for Level 4 may be found in the planning support tools. These DSSs aim to support planning across multiple organizational entities and may be designed for addressing decisions concerning land-use and transportation, tourism, and public health-services, to name a few examples.

Decisions related to system level transitions typically involve a wide range of stakeholders with potentially conflicting values, a strong urgency to address the problem at hand, and high levels of uncertainty in the scientific information necessary to fully appraise alternative courses of action. These elements are synthesized as Post-Normal Science (henceforth PNS) by Funtowicz and Ravetz (1993). In PNS theory, we are reminded that any information and choice of presentation is value-laden, that worthwhile knowledge exists in the community, and that uncertainty should be accepted in decision-making (Ravetz 1999) rather than rejected or hidden.

23.3 Discussion

23.3.1 Developing Decision Support Systems for Systems Change: Challenges

In searching for an explanation as to why few DSSs for societal transition are in use, it is necessary to understand the activities of problem-solving and decision-making. Herbert A. Simon (1960), considered a pioneer in DSS science, distinguished three phases of decision-making processes. In the first phase, *intelligence activity* is performed to search the environment for conditions calling for a decision. In operations research, this refers to problem structuring activities, which entails identifying stakeholders and their problems, goals, and values. This also involves creating an understanding of the external environment and constraints to potential solutions (Belton and Stewart 2002). Simon's second decision-making phase involves *design activity*, where possible courses of action are developed and analyzed. This relates to the model building phase in operations research, where alternatives and values are specified in models (Belton and Stewart 2002). Lastly, the *choice activity* takes place, where a particular course of action among those identified is selected. In operations research, this involves the application of models to discern preferable courses of action. Simon underlined that these steps are sequential and iterative, and that all phases occur within each phase (Simon 1960). Since Simon, authors such as Witte (1972) have challenged the established idea of sequential phases, favouring a model where actions are made in parallel.

While dividing the decision-making process into distinctive phases may support the design of a DSS to drive sustainable transitions, the complexity in both problem structuring (intelligence) and model building (design) activities greatly increases between Level 3 and Level 4, i.e. from the organizational to the systems level. This is partly due to the number of stakeholders potentially involved as well as the variety of system types to address, which may diminish the hopes of achieving agreement on defining a problem and how it may be solved. According to Pidd (2003), decision situations where there is stakeholder agreement on both these dimensions may be considered puzzles – the challenge is merely to select a best course of action. Next, there are problems – decision situations where a unified understanding of the problem and solution is achievable, but requires effort to formulate and select promising solutions. Lastly, there are messes, where there is no consensus on the problem itself, nor the solutions to potentially solve them. This links back to the PNS theory where a high number of stakeholders with conflicting values interact to reach decisions. Moving from lower to higher Levels in the CapSEM Model implies greater problem complexity as there are more degrees of freedom and more stakeholders whose (potentially conflicting) perspectives need to be addressed to define the purpose and scope of the DSS.

Rittel and Webber (1973) famously coined problems of planning and policy-making as "wicked problems". In their seminal article "Dilemmas in a general theory of planning", the abstract succinctly states their viewpoint:

> The search for scientific bases for confronting problems of social policy is bound to fail, because of the nature of these problems. They are "wicked" problems, whereas science has developed to deal with "tame" problems. Policy problems cannot be definitively described. Moreover, in a pluralistic society there is nothing like the undisputable public good; there is no objective definition of equity; policies that respond to social problems cannot be meaningfully correct or false; and it makes no sense to talk about "optimal solutions" to social problems unless severe qualifications are imposed first. Even worse, there are no "solutions" in the sense of definitive and objective answers.

23.4 Pathways to Developing Decision Support Systems for Systems Change

Against this backdrop, it is worth asking whether it is possible to develop useful DSSs for system change or if the logic underpinning DSSs makes its shortcomings too big. While the shortcomings are seemingly clear, some remediation may exist. The following sections aim to explore potential pathways to address this question in the research and practice of DSSs through rethinking the *who*, *how* and *what* of DSS development.

23.4.1 Who: Exploring Co-creative Developmental Design

Several scholars have explored the existing implementation gap of decision support systems at the planning and policy-making level. A key finding from this research is that many systems seem to be developed *for* users, rather than *with* them (Te Brömmelstroet 2010). Another problem is that they are technology-driven as opposed to user-driven and thereby end up representing state-of-the-art without consideration to state-of-the-practice (Te Brömmelstroet 2010; Geertman and Stillwell 2020). This mismatch between research and practice is also observed for DSSs in general (Arnott and Pervan 2008). These challenges call for new methods to engage users and problem-owners in the research and development of DSSs. One way that PNS theory advocates effective problem-solving in these circumstances is by ensuring the quality control of the scientific information and policy recommendations through the extended peer community. Scientific data and models may hide important details of how changes may be felt "on the ground", and valuable insights held in the local community may be lost (Funtowicz and Ravetz 1993). In addition, these types of decisions can have serious consequences on a wide range of stakeholders, beyond the decision makers. DSSs should support decisions on issues that are relevant to practitioners and therefore include their knowledge as well as that of the local community.

Engaging users in the research and development of DSSs may be done in several ways. At the most basic level is the traditional involvement where input from users is added to an existing arrangement. In these types of development projects, a team of researchers/developers facilitate user engagement, e.g., through pre-designed input and feedback activities. Next, there is collaborative research where users and researchers/developers initiate, perform and control projects together. Lastly, there is user-controlled research where users both initiate and control the research and development.

While these forms of engagement are relatively well known from public health research, it is still unclear how they translate to decision science and other disciplines involved in creating DSSs. While basic user feedback is relatively commonplace in a DSS development, involving users more profoundly throughout the entire development process calls for new ways of designing development projects and engagement methods. What are the potential roles of users beyond offering information about their needs and requirements and feedback to subsequent mockups and prototypes? How do these potential new roles change the interaction between researchers/developers and users in DSS development? How to generate ownership and participation in the design phase without creating fatigue among the user group? While some of these stronger user engagement approaches may pose new challenges to developmental design, they may also open up for increased literacy among users in the DSS technology itself and the problem context in which it exists in addition to securing improved relevance once it has been developed.

23.4.2 How: Exploring Soft System Thinking and Methodologies

While known rules and procedures from operations research and "hard sciences" have apparent shortcomings in the face of wicked problems in planning and policymaking at the systems level, soft systems methodologies may offer valuable approaches to address them. Checkland's soft systems methodology (Checkland 1999) has, in fact, been deployed in operations research exercises to expand on conventional problem structuring efforts (see e.g. Belton and Stewart 2002). Checkland argues that while solving problems in hard systems is possible through offering models of the world, soft systems problem solving requires developing models relevant to arguing about the world. Essentially, soft systems models can at most represent a particular view of the world (Checkland 1985). These models, achieved through soft systems methods, may occasionally condense to formulate clear objectives necessary in hard systems thinking. This linkage between soft and hard systems thinking offers a pathway to explore (and potentially expand) models and elements of the messy, wicked soft systems that may be translated to and managed in the structured environment of a DSS.

In PNS, the usual domination of “hard facts” over “soft values” is inverted. Due to the high level of uncertainty, and the high decision stakes, some policies with life-changing consequences for high numbers of people will be decided on very uncertain information. Value commitments and trust will determine the acceptance of these policies rather than scientific certainty. Therefore, as pointed out by Funtowicz and Ravetz (1993), the traditional scientific inputs become “soft” in the context of “hard” decisions.

23.4.3 *What: Exploring the Potential Transformative Role of DSSs*

Up until this point, there has been little debate about the DSS’s role in supporting sustainable transformation at the system level. A critical question is what such a DSS can do, beyond offering new sustainability-related information or knowledge to decision-makers at various system levels. To explore this potential, the SAMR model may be helpful (Puentedura 2013). Robert R. Puentedura developed the model as part of his work in the Maine Learning Technologies initiative (Puentedura 2006). The model was initially developed, and is still primarily deployed, for educators to rethink the role of technology in learning. The model provides a ladder where the role of technology in learning moves from enhancement to transformation. What is intriguing with the model in DSSs is the ability to consider the potential impact on both cognitive and social processes brought about by its use. Table 23.1 shows the basic achievements at each step of the ladder.

While DSSs offer computational capacities far beyond the abilities of the human mind, a system that merely performs calculations to alleviate the cognitive burden to decision-makers will only *substitute* this part of the decision-making process. As an example, a process optimization software that helps tune operational parameters in a physical system (e.g., a ship, building, or production plant) to reduce energy consumption may be said to act in a pure substitutive manner. The role of the decision-maker is to act upon this information without necessarily rethinking the entire design and functioning of the (physical) system of study. The same may be said about a planning support tool that offers more precise and/or comprehensive information about a transportation system. As long as the information is merely

Table 23.1 The SAMR model for technology in learning. (Modified from Puentedura 2013)

Substitution	Technology acts as a direct substitute, with no functional change	Enhancement
Augmentation	Technology acts as a direct substitute, with functional improvement	
Modification	Technology allows for significant task redesign	Transformation
Redefinition	Technology allows for the creation of new tasks, previously inconceivable	

absorbed in existing planning and policy-making processes, the DSS will only substitute existing information and technologies utilized in these processes.

A DSS that *augments* decision-making also provides functional improvement to the decision process. For planning and policy making, this could be exemplified by a DSS that offers the ability to combine information in new ways and present them in a visual-intuitive form to create a better understanding of the (system) problems at hand and its potential solutions. An interactive digital twin-based planning support tool using e.g. augmented reality technology for land-use and transportation planning an example of such a tool. The functional change in this type of DSS is brought about by permitting new ways to interact with and interpret data.

To achieve task *modification* in planning and policy decision-making, the DSS must also enable significant redesign of these decision-making processes. Although this could be done in numerous ways, an example could be an open solution where citizens may enter data and access and interact with the system to offer their feedback, questions, and comments to ongoing processes. A good example of a planning support tool utilized in this manner is the CityPlanner map service piloted in Ulstein municipality in Møre & Romsdal county in Norway. During the public consultation process of the area zoning plan in the municipality in 2018, the 3D mapping tool CityPlanner was deployed to permit citizens to comment on plans for new trekking paths in the local mountains (Ulstein Municipality 2020). The planners also used social media to promote citizen engagement through the tool.

Lastly, a DSS that *redefines* public planning and policy-making helps create new processes previously inconceivable. It could potentially offer new ways for decision-makers and other stakeholders to generate, exchange and negotiate information. Considering contemporary planning and policy-making processes, there is great improvement potential with respect to the transparency and engagement achieved in these processes across the wide range of stakeholders involved. The same could be said for exploring how the DSSs are deployed throughout the problem-solving processes they are designed to support. While DSSs often are designed to predefined (recurring) problems, few tools are designed for more open-ended problem exploration and structuring as part of early planning and policy-making activities.

23.5 Conclusion

Designing and implementing decision support systems for sustainable transformation at the system level is a complex task which requires enabling approaches and tools. In this chapter, three such approaches have been proposed within the framework of Post-Normal Science. First, the *who* of the system needs to be carefully curated. This pertains not only to system users once it is designed, but also who is involved during the design and development of the DSS and what roles they are assigned. Co-creative and participatory forms of research and engagement are critical for establishing systems that tackle the task complexity for system stakeholders, ensures meaningful problem-solving functionality and impactful use. Next, the *how* of system development with system stakeholders needs to be addressed. Soft systems engineering methodologies have been used in multiple domains to engage stakeholders in system development. The domain offers language, procedures and tools to translate between a messy problem context and the structured environment of DSSs. Lastly, the *what* of system development needs to be further explored in the context of transformative change. This concerns the role of the DSS in the decision-making processes they are used and the form and functionality it contains to achieve its role. The SAMR model offers a useful taxonomy to address this question as it distinguishes levels of learning and task performance enabled by ICT tools in problem solving processes. The model was initially developed for instructors to curate and design tasks for learners using ICT tools. In the context of planning support, a DSS is an ICT tool used to aid decision makers in addressing sustainable transformation in a pedagogical manner. The remaining challenge is to understand how to move from enhancement to transformation, which implications this has for the wider decision-making processes the DSS is utilized within, and how this dynamically influences further DSS development and application.

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Chapter 24
The Way Forward

Annik Magerholm Fet and Martina Keitsch

Abstract This chapter points to the way ahead by introducing five recommendations to meet the requirements set forward by the Stockholm+50 agenda. The requirements identify co-working as vital to addressing the planetary crisis of climate change, biodiversity loss and pollution, better collaboration and cooperation across all sectors, reinventing to a circular economy meaning decouple economic development from its destructive footprint, accessibility of data, and raising a common awareness for our planet. In response to this potential need, they present five transition options that might facilitate realising the requirements above and recognise a need for: (1) system change, (2) radical interdisciplinarity and transdisciplinarity, (3) net positive leadership, (4) digitalization for sustainability, and (5) fair and inclusive transitions. Business leaders, their stakeholders and other groups should consider meeting these needs through their work in partnership with other actors.

24.1 Introduction

Chapter 21 focused on how the CapSEM Model tools for continuous improvement can contribute to a transition to sustainability. Chapter 21 also looked at drivers for transition achieved through the use of the CapSEM toolbox and additional drivers sourced from new policy frameworks and international roadmaps, SDG-roadmaps and the European Green Deal. Chapters 22 and 23 presented two *means* for enhancing this transition: firstly, business models innovation for sustainability, and secondly multi-criteria decision supporting tools. This final chapter explores

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possibilities inherent in forward-looking approaches, discussed new, innovative recommendation and which possible options to accelerate transitions to true sustainability.

24.2 Bottom-Up Versus Top-Down Transitions and Transition Instruments

When following the CapSEM Model, the stepwise transitions related to processes, products or organisational changes, can be viewed as a *bottom-up* approach with incremental, and measurable, achievements in sustainability. Transition towards sustainability from a *top-down* approach might look quite different. Global challenges such as climate change, scarcity of resources, pollution of oceans and land, sea-level rise, changes in the global economy, all call for radical changes and necessitate longer-term transition solutions. Global leaders are continuously searching for new perspectives and models for collaboration for sustainability. To develop such models, business and society cannot work in isolation from each other: they must act together in order to pave the way ahead.

At the top of the agenda for forward looking leaders, is how to carry out effective system changes. To this end, both *bottom-up* and *top-down* approaches are needed. The driving forces can, to some extent, be different. Figure 24.1 illustrates both *top-down* and *bottom-up* approaches. On one hand, a *bottom-up* approach might start as a result of consumer demand, for example, by putting pressure on business to document the environmental impacts or climate footprints of the products or services which they provide. When using the CapSEM Model approach, this frequently leads to incremental, and continuous, changes. On the other hand, civil society at large, exposed to pollution and increased waste streams, climate changes and loss of biodiversity, represents a driver for changes on national and international levels. This, in turn, puts pressure on governmental bodies' *top-down* instruments to consider more radical system changes. *Top-down* visions, strategies and frameworks must be connected to *bottom-up* delivery of solutions if viable solutions for systems change are to be properly implemented.

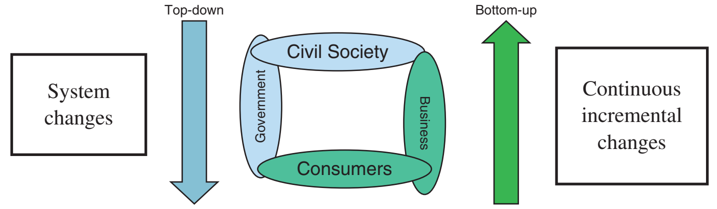

Fig. 24.1 Model of actors and their roles in the *top-down* and *bottom-up* approach

Policy makers face a considerable challenge in developing feasible combinations of instruments and incentives for facilitating transitions to sustainability. This requires, amongst a range of actions, integrating and implementing international and national regulations in both local, and regional, industrial organisations. To aid this endeavour, the following administrative, informative and economic instruments are already currently available.

The *administrative instruments* are regulatory and take the form of laws, licenses, binding regulations, and guidelines, towards the establishment and funding of a robust system of enforcement.

At a transnational level, the European Green Deal, and the Taxonomy and Transparency Act comprise holistic transition strategies for a new sustainable socio-economic model.

The *informative instruments* aim to raise awareness of the benefits of sustainability through the creation of centres of expertise. Leaflets and websites that disseminate news and best practice for information and knowledge generating examples of this, are educational programmes that train sustainability experts.

Economic instruments aim to motivate projects towards using economic instruments such as tax incentives, soft loan programmes, and funding for research. Other economic instruments may apply at consumer level such as refund and sharing systems, or taxes imposed on fossil fuel products, or other harmful and hazardous chemicals.

24.3 From Stockholm 1972 to Stockholm +50

The United Nations Conference on the Human Environment which took place in Stockholm 1972 was organized as an answer to an emerging need for a top-down view on the global situation regarding the state of the environment. As reported from the Stockholm+50 Conference that took place in 2022 (United Nations 2022), the 1972-conference succeeded in bringing the challenges facing the global environment. The importance of the 1972 conference was emphasised as follows in the report from Stockholm 2022:

> Before 1972, most people saw environmental issues as local -- pollution of rivers, lakes, and streams, air pollution over their cities, and oil spills affecting their coastline. The Stockholm Conference and the creation of the United Nations Environment Programme (UNEP) – one of the conference's most important and lasting legacies – was instrumental in raising awareness that many environmental issues are global and require intergovernmental cooperation to address them. (United Nations 2022)

The Stockholm Declaration (UNEP 1972) proclaimed 26 principles. Principle 25 states that 'States shall ensure that international organizations play a co-ordinated efficient and dynamic role for the protection and improvement of the environment' The UNEP declaration (1972) also proclaimed:

> The protection and improvement of the human environment is a major issue which affects the well-being of peoples and economic development throughout the world; it is the urgent desire of the peoples of the whole world and the duly of all Governments.

Following 1972, numerous protocols, conventions and multilateral environmental agreements have been developed. The 1992 UN Conference on Environment and Development, also known as the Earth Summit, commemorated the twentieth anniversary of the Stockholm Conference. The Earth Summit adopted the Rio Declaration, which was a direct output of the Stockholm Declaration. Similarly, the programme of action adopted in Rio, Agenda 21, updated the Stockholm Action Plan to address sustainable development issues on the eve of the twenty-first century (United Nations 1973, 2022).

Twenty years after the Earth Summit, and 40 years after Stockholm, governments gathered again in Rio de Janeiro for the UN Conference on Sustainable Development (Rio + 20). This conference set in motion the process for negotiating the 2030 Agenda for Sustainable Development and its 17 Sustainable Development Goals (SDGs), which were adopted in 2015.

Recommendations by the UN for accelerating the actions for a *Healthy Planet and Prosperity for All* are summarised in five requirements (United Nations 2022):

(a) Co-working between countries and other stakeholders to address the triple planetary crisis of climate change, biodiversity loss and pollution.
(b) Better collaboration and cooperation across environmental efforts within the UN, the private sector, and other stakeholders. There is a strength in coming together and calling for change.
(c) Reinventing an economy for the twenty-first century, e.g. by a green or a circular economy; meaning decouple economic development from its destructive footprint.
(d) Science, technology, and data need to be both accessible and used effectively. In addition to strengthening the role of science across the board of enterprises.
(e) Raising public awareness about the global nature of environmental problems.

To meet the requirements above, the need for implementation in practice is paramount, which, in turn, necessitates collaboration with business.

24.4 Long-Term Transition to Sustainability

A common roadmap which could contribute towards meeting these five recommendations set out by the UN, would make it far easier for actors and stakeholders to initiate long term transitions. However, given the complexity of these recommendations, a single straightforward roadmap is problematic to design. Moreover, in addition to deliberate modelling and development of mechanisms, emerging transition trends and the way in which business and society deal with them, will continue to influence sustainability paths in the future. Societal stakeholders will have to utilize changes that appear in the global (business) community: that could potentially impact the quest for developments in advancing sustainability. In response to this potential need, the authors of this chapter have identified five transition options that might facilitate realising the requirements above:

1. System change
2. Radical interdisciplinarity and transdisciplinarity
3. Net positive leadership
4. Digitalization for sustainability
5. Fair and inclusive transitions

24.4.1 System Change

System change meets a need for coworking between countries and societal stakeholders to address the triple planetary crisis of climate change, biodiversity loss and pollution, as indicated in point (a), Sect. 24.3. A dynamic understanding of systems and the interaction of systems reveals to us that a great deal more than incremental changes are needed if we are to depart from the status quo. McPhearson et al. (2021) suggest five principles for initiating systems level transformation by rethinking growth, efficiency, the state, the common, and justice.

Implementing these principles globally furthers the organization of interactions by societal stakeholders so that sustainability can be taken up on a long-term basis.

A systemic understanding of transitions to sustainability commences with individual actors and comprehends that change occurs on all levels. For businesses following a top-down approach of the CapSEM Model, it concerns perceiving their place and role as change makers in a much larger system, e.g. in a larger production chain system, or as local stakeholders in the community, and realising their roles as potential game-changers when it comes to consumer behaviour across the whole of society. SDG 12 (Responsible consumption and production) with its subgoals and targets pave the way as to how business can integrate systemic sustainability premises in their strategies and deliverables. Systemic sustainability embraces "the possibility that human and other forms of life will flourish on the Earth forever" (Ehrenfeld and Hoffman 2013).

24.4.2 Radical Interdisciplinarity and Transdisciplinarity

Improving cooperation across environmental efforts ((Sect. 24.3, point (b)) calls for collaboration between disciplines: interdisciplinarity and trans-disciplinarity is a must to meet the need for science, technology, and data to be both more accessible and used effectively. Radical interdisciplinarity (RI) is merging discrete disciplines in order to generate new knowledge. It thereby combines methodologies of traditional scholarship with narrative, creative approaches. This fusion of discrete branches of knowledge can encourage genuinely new insights on, for example, sustainability and gender issues etc. (Keitsch 2022). The systems-orientation of RI offers many opportunities, and disciplines might eventually move to transdisciplinarity, which encourages cross-communication and design, rather than the persistence of disciplinary identities (Jantsch 1972). Transdisciplinarity is defined as a

> critical and self-reflexive research approach that relates societal with scientific problems; it produces new knowledge by integrating different scientific and extra-scientific insights; its aim is to contribute to both societal and scientific progress'. (Jahn et al. 2012)

Alongside a greater need for empirical data comes a necessity for broader and normatively oriented problem framing of top-down transitions to sustainability together with the demand for scientific results which can be used, and useful, for society. How, and to what extent, academic as well as non-academic actors manage to develop methodologies and engage in open and responsive discourses are key factors for success, both for sustainability scientists and for societal transition processes alike. Some authors claim that long term transitions require interest in the normative direction of innovation (Grin et al. 2010). The potential of innovation rests not solely in economic benefit or political power, but in overall desirable societal changes and citizens well-being, induced by this innovative activity.

Successful movement across levels in the CapSEM Model calls for an understanding and competence rooted in science, technology, strategic management, and governance, which encompass a mix of transdisciplinary competence. Transitions induced by methods in the CapSEM Model may be minimal or 'small-range' on some levels, in regards to the mutual knowledge generation and its wider transformational effect (Stokols 2006; Lang et al. 2012). However, the stepwise CapSEM Model provides a framework for enhancing activities and contributes towards motivating stakeholders to engage in companies' sustainability strategies (Fet and Knudson 2021).

Thereby, the CapSEM Model displays great potential for generation, implementation, and reflection of new transdisciplinary knowledge on sustainability between various actors and diverse international contexts.

24.4.3 Net Positive Leadership

Net positive leadership contributes to meet the need for reinventing the economy for the twenty-first century, e.g. via green or circular economies and decoupling economic development from its destructive footprint (Sect. 24.3, point (c)). Green competitiveness illustrates how net positivity can be approached in a network of companies. According to Polman and Winston, addressing sustainability challenges via qualitative growth and social responsibility, comprises a huge economic opportunity for companies (Harvard Business Review, September–October 2021). Core technologies such as renewable energy, batteries, smarter artificial intelligence (AI), big data, are getting cheaper and can be implemented at large scale. Companies that have embraced action on environmental, social, and governance also increasingly demonstrate that sustainability makes for profitable business. Polman and Winston signify sustainability focused companies as ‘Net Positive’: (Such a company…) “improves well-being for everyone it impacts and at all scales – every product, every operation, every region and country, and for every stakeholder, including employees, suppliers, communities, customers, and even future generations and the planet itself.” (Polman and Winston 2021, p. 7). The foundation for Polman and Winston’s novel business architecture is a, somewhat radical, appeal to a strongly profit oriented economic community. Polman and Winston suggest companies should withdraw their seclusion: they have a global responsibility.

> Responsibility is a core divider between a typical business and a net positive one. After all, the current model of shareholder capitalism generates tremendous financial value for business by pointedly not taking ownership and treating issues such as pollution or inequity as ‘someone else’s problem’. So, taking responsibility is the first step. (Polman and Winston 2021)

Strategically, responsibility can be met by rethinking what a business is, how international change can be driven and how other stakeholders can be included in the decision-making processes.

> We’ve earned the distrust of society …With everyone at the table, we can shift entire systems toward well-being for all. The potential for positive impact is exponentially larger than going it alone. Historically, governments and multilateral institutions have taken the initiative, but in an increasingly challenging national and international political environment, leading companies are expected to step up and help make political action less risky for peers and governments. This is the ultimate work of a net positive company. (Ibid., 168)

Balch (2013) discusses possible drawbacks of net positivity that are worth to address. First it seems to be a real challenge that companies will only mitigate their most relevant impacts; Coca-Cola changes its environmental policy only on water, Kingfisher and Ikea are limiting their ambitions to forests, etc. (Balch 2013). Moreover, there are industries that might have a hard time to exercise global responsibility such as weapon producers. Further, it will be difficult to measure net positivity success. What are the criteria for its impact on society?

These few points already indicate that questions and challenges related to companies’ responsibility have to be discussed by society at large, not solely by companies. Yet, the positive effect of net positivity is its radical approach, it urges the entire business culture, while corporate social responsibility (CSR) strategies often do not reach to the core of a business organization and permeate all levels.

24.4.4 Digitalization for Sustainability

Digitalization for sustainability addresses the need for better collaboration and cooperation on environmental efforts within the UN, the private sector, and other stakeholders (Sect. 24.3, point (d)). Data driven change towards sustainability is gaining momentum in the digitalization context. Utilizing data technologies to make more efficient use of resources is the main goal of Industry 4.0. Computerization is increasingly impacting manufacturing. Business is quickly adopting mechanisms such as Internet of Things (IoT), cloud computing and analytics, and AI and machine learning for production processes and operations. IoT-related technologies promoting circular economy (CE) seem particularly promising (Rejeb et al. 2022). The successful implementation of IoT requires big data and novel analyses to detect patterns and trends that can ensure that the implementation of CE concepts is technologically and economically feasible. The crucial role of big data in enabling the transition to e.g. CE is pointed out by several authors (Rejeb et al. 2022). However, they also point to risks such as privacy protection and data security when making products 'smart'. Technology and ICT enablers such as IoT, Augmented Reality, Digital Twins are fruitful for sustainability but they require the development of capabilities to identify, use, and assimilate internal and external information.

24.4.5 Fair and Inclusive Transitions to Sustainability

Fair and inclusive transitions to sustainability address, among others, public awareness about the global nature of environmental problems and contributes to acknowledge environmental challenges (see point (e) in Sect. 24.3). The twenty-first century is facing various social challenges on a global scale. That represents persistent problems such as unstable financial and economic systems, ageing populations, poverty and work migration flows. Grin et al. (2010) suggest that these challenges involve various interdepended actors, domains, and scales, and are not directly controllable. Schäpke et al. (2016) understand sustainability transitions as facilitating change in societal systems, yet the outcome is uncertain. Transition management is regarded as necessary to direct change by applying empowerment, social learning, and social capital development. Transition management helps governments to accelerate change towards sustainability. This takes place on global and national but specifically on local levels. Communities are increasingly encouraging social innovation to manage resources for the public good. Transition management on the local level for example in form of *transition towns*, for example through engaging their communities in home-grown, citizen-led education, action, and multi-stakeholder planning to increase local self-reliance and resilience (Weerakoon et al. 2021). The *transition towns* illustrate an example how the two strands of top-down and bottom-up approaches of sustainability can be connected to create potential for dialogue and dynamic interactions between the respective actors (Alexander and Rutherford 2014).

Fairness and inclusiveness are also in the core of the SDGs. The SDG-CapSEM connection is discussed in Chapter 21, and can be useful guidance for companies when addressing these themes.

24.5 Conclusion

The CapSEM Model can be regarded as the backbone for many existing roadmaps and standards for strategic and systemic innovation and implementation, as well as a foundation for business decisions for actions at the different systems levels. It also facilitates future sustainability development as ways in which to integrate knowledge across the breadth of sustainability management tools and compile them into coherent customized frameworks for different users. Small stepwise changes have been important parts of the transition towards sustainability. This publication has sought to demonstrate that over many years, these have led to incremental, critical, changes in business performance. The hope is that they will continue to be a key and important way of meeting the global challenges the world is currently facing and will continue to face for the foreseeable future. The CapSEM Model has been developed as a guiding model to help business to work systematically with the tools to achieve a stepwise transition to sustainability. It has mainly focused on the environmental aspects and the related toolbox. However, both social and economic aspects connected to the transition to sustainability could be addressed by a similar systemic mindset model. New tools and roadmaps to be added to the toolbox are steadily under development and can be implemented, mainly based on natural science principles.

Overall, the model can contribute towards the implementation of global frameworks for sustainable development, including UN Sustainable Development Goals, and to combat e.g., climate change, biodiversity loss and pollution. The model acts here as a catalyst for business transition experiments for sustainability, while future development should focus more explicitly on mutual learning between companies themselves and between companies and society. For example, combining the CapSEM Model with frugal, disruptive, and inclusive innovation strategies (Ries 2011; Bound and Thornton 2012) that can generate immediate learning and lead to practical insights, without excessive resource and time expenses, which is relevant for all SMEs, and especially sought after in developing countries. The CapSEM model could here facilitate adoption of the SDGs for business in different cultural and economic settings, which is in line with the motto of the Sustainable Development Goals: 'Leave no one behind'.

There is no doubt that the CapSEM Model contains the potential for expansion in a variety of directions. It is flexible and dynamic enough to contribute towards global transitions for sustainable development, amply demonstrated throughout this publication and harking back to where this journey began. Future developments can be achieved and underpinned by fostering multi-actor collaborative partnerships, expanding education, providing training materials and spreading knowledge about sustainability around the globe.

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