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Life Cycle Initiative

Towards a Life Cycle Sustainability Assessment

Making informed choices on products

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Acronyms

CALCAS	CALCAS, Coordination Action for innovation in Life Cycle Analysis for Sustainability
CBS	Cost breakdown structure
CR	Critical review
EC	European Commission
ELVs	End-of-life vehicles
EoL	End of life
EPD	Environmental Product Declaration
EU	European Union
FAETP	Freshwater aquatic ecotoxicity potential
FSC	Forest Stewardship Council
HTP	Human toxicity potential
ISO	International Organization for Standardization
(environmental) LCA	Environmental life cycle assessment
LCA	Life cycle assessment
LCC	Life cycle costing
LCI	Life cycle inventory analysis
LCIA	Life cycle impact assessment
LCM	Life cycle management
LCSA	Life cycle sustainability assessment
LCT	Life cycle thinking
NGO	Non governmental organization
R&D	Research and development
REPA	Resource and environmental profile analysis
SCP	Sustainable consumption and production
SETAC	Society for Environmental Toxicology and Chemistry

S-LCA	Social life cycle assessment
TETP	Terrestrial ecotoxicity potential
UN	United Nations
UNCED	United Nations Conference on Environment and Development
UNEP	United Nations Environment Programme
UNEP-DTIE	United Nations Environment Programme – Division of Technology, Industry and Economics
WBCSD	World Business Council for Sustainable Development
WE LCA	Working Environment in Life Cycle Assessment
WEEE	Waste electrical and electronic equipment

Executive Summary

In this introduction to the concept of life cycle sustainability assessment (LCSA), we acknowledge the foundations laid by previous works and initiatives. One such initiative has been the ISO 14040 series (Environmental management – Life cycle assessment – Principles and framework), which in addition to the ISO 26000: Social Responsibility Guidance Standard, and the contribution of a number of international initiatives (Appendix A) have been essential for the development of this publication.

The life cycle of a product involves flows of material, energy and money. Nonetheless, the picture is not complete unless we look also at the production and consumption impacts on all actors along the 'value chain' – workers, local communities, consumers and society itself.

Different life cycle assessment techniques allow individuals and enterprises to assess the impact of their purchasing decisions and production methods along different aspects of this value chain. An (Environmental) life cycle assessment (LCA) looks at potential impacts to the environment as a result of the extraction of resources, transportation, production, use, recycling and discarding of products; life cycle costing (LCC) is used to assess the cost implications of this life cycle; and social life cycle assessment (S-LCA) examines the social consequences.

However, in order to get the 'whole picture', it is vital to extend current life cycle thinking to encompass all three pillars of sustainability: (i) environmental, (ii) economic and (iii) social. This means carrying out an assessment based on environmental, economic and social issues – by conducting an overarching life cycle sustainability assessment (LCSA). This publication shows how all three techniques – which all share similar methodological frameworks and aims – can be combined to make the move towards an overarching LCSA possible.

Because it is holistic, systemic and rigorous, (environmental) LCA is the preferred technique when it comes to compiling and assessing information about potential environmental impacts of a product. It has been standardized in the ISO 14040 and 14044 and is applied by practitioners globally.

Life cycle costing as a technique to calculate and manage costs, especially for large investments has been used to support decision-makers in procurement for decades, with a rigorous focus on private costs. Prerequisites for better alignment with (environmental) LCA are currently being researched and will help the further development of the method. As an emerging technique, S-LCA will play a key role in complementing material- and energy-flow-related information.

Since the late 1990s, the Life Cycle Initiative partnership of the United Nations Environment Programme (UNEP) and the Society for Environmental Toxicology and Chemistry (SETAC) has enhanced the role of life cycle based approaches and thinking in several ways. Two examples are the partnership's contributions to the Marrakech Process on Sustainable Consumption and Production (SCP) and inputs for the development of a 10-Year Framework of Programmes on SCP (10YFP).

This current publication, *Towards a Life Cycle Sustainability Assessment*, expands this work by bringing the concept of LCSA methods to the fore. In doing so, it will contribute to the sustainable development discussions of the United Nations Conference on Sustainable Development (Summit) in 2012 ('Rio+20').

The text will also contribute to the UNEP Green Economy Initiative – which strives to build economies that bring improved human well-being, reduce inequalities over the long term and which keep future generations safe from environmental risk and ecological scarcity.

Specifically, *Towards a Life Cycle Sustainability Assessment* hopes to increase decision-makers' awareness of more sustainable life cycle stages. It will also support stakeholders looking for approaches that will provide holistic assessments of the implications of a product's life cycle for the environment and the society. Finally, it will offer guidance to enterprises and people who are trying to reduce environmental degradation and the use of natural resources in their production practices and increase the environmental, economic and social benefits for society and local communities.

This publication can be used as a springboard for stakeholders to engage in a holistic and balanced assessment of product life cycles and to consider the three pillars of sustainability in a unique and instructive approach. In this way, this publication will provide further guidance on the road towards the consolidation of LCSAs.

LCSA has the potential to be used by decision-makers in governments, agencies for international cooperation, business and consumers' associations. While more research and applications are needed, its application is already feasible and encouraged to speed the learning curve of society.

The publication includes eight case studies to illustrate how current and emerging life cycle assessment techniques are being implemented worldwide from Asia through Europe and Latin America.

Sommaire Exécutif

Dans cette introduction au concept d'Analyse de la Durabilité dans le Cycle de Vie (ADCV), nous reconnaissons les fondations posées par les travaux et initiatives antérieurs.

Les initiatives suivantes, ISO 14040 (Management environnemental – Analyse du cycle de vie – Principes et cadre) ajoutées aux séries ISO 26000 (Lignes directrices relatives à la responsabilité sociétale) et un important nombre de projets internationaux ont été essentiels dans le développement de cette publication.

Le cycle de vie d'un produit engage différents flux d'énergie, de matériaux, et d'argent. Néanmoins, le tableau serait incomplet si l'on omettait de prendre en compte les impacts de la production et de la consommation sur tous les acteurs de la chaine de valeur: les ouvriers, les communautés locales, les consommateurs et la société.

Les différentes techniques d'évaluation du cycle de la vie permettent aux individus et aux entreprises d'évaluer les impacts de leurs décisions d'achat ainsi que de leurs méthodes de production tout au long des différents aspects de cette chaine de valeur. L'analyse (environnementale) du cycle de vie (ACV) considère les impacts comme conséquences de l'extraction de ressources, du transport, de la production, du recyclage, de l'usage et de l'élimination des déchets; l'analyse des coûts du cycle de vie (ACCV) est utilisée pour évaluer les implications des coûts au long de ce cycle de vie; et l'analyse sociale du cycle de vie (ASCV) étudie les conséquences sociales.

Cependant, dans le but d'obtenir un tableau plus complet, il est important d'étendre la pensée de 'cycle de vie' afin qu'elle englobe les trois piliers de la durabilité: (i) environnement, (ii) économie, et (iii) social. Ce qui revient à établir un bilan fondé sur les facteurs économiques et sociaux ainsi qu'environnementaux, en mettant sur pied l'ADCV. Cette publication vise à expliquer comment y parvenir et démontrera comment ces trois techniques – avec les mêmes buts et trames méthodologiques – peuvent être combinées pour rendre possible l'ADCV.

Parce qu'elle est holistique, systémique et rigoureuse l'ACV (environnementale) est la technique privilégiée lorsqu'il s'agit de compiler et d'évaluer des informations sur les impacts environnementaux potentiels d'un produit. Elle fut standardisée au travers des normes ISO 14040 et 14044 et est appliquée par des acteurs dans le monde entier.

L'ACCV est une technique qui calcule et gère les coûts, principalement dans le cas des larges investissements. A travers une approche rigoureuse de coûts réels, cette technique a été utilisée pendant des décennies afin d'aider les responsables des services d'achats. Afin de permettre un meilleur alignement avec l'ACV (environnementale), un futur développement de l'ACCV est nécessaire. L'utilisation de la technique émergente de l'ASCV jouerait un rôle clé car elle complémenterait les informations reliées aux flux des matériaux et de l'énergie.

Depuis la fin des années 1990, le partenariat du cycle de vie du Programme des Nations Unies pour l'environnement et de La Société de Toxicologie et Chimie de l'Environnement ont amélioré le rôle des approches de cycle de vie de différentes manières: pour exemple, grâce à la contribution du partenariat au Processus de Marrakech des Nations Unies sur la Consommation et Production Durable

(CPD) ou le développement d'un cadre décennal de programmes de CPD (10-YFP).

La publication, *Vers une analyse de la durabilité dans le cycle de vie du produit*, développe ce travail en mettant le concept d'ADCV au premier plan. Dans cette optique, elle contribuera également aux discussions sur le développement durable qui auront lieu en 2012 (Rio+20) lors du sommet des Nations Unies sur le développement durable.

Ce texte contribuera aussi à l'initiative sur l'économie verte du PNUE, qui vise à construire des modèles économiques qui améliorent la condition humaine, tout en réduisant les inégalités sur le long terme et en protègant les futures générations par la prévention des risques environnementaux et les pénuries écologiques.

Plus spécifiquement, la publication *Vers une analyse de la durabilité dans le cycle de vie du produit espère* pouvoir sensibiliser les 'preneurs de décisions' sur des méthodes de production durable. Il aidera aussi les parties prenantes intéressées en cherchant des approches qui permettent des évaluations holistiques sur les conséquences environnementales et sociales du cycle de vie d'un produit.

Enfin, il offrira une orientation en conseillant les personnes et les entreprises qui essaient de diminuer la dégradation de l'environnement et l'utilisation des ressources naturelles dans leurs méthodes de production, l'augmentation des bénéfices environnementaux et socio-économiques pour la société et les communautés locales.

Cette publication peut être utilisée comme un appui pour les parties prenantes pour se lancer dans une évaluation holistique et équilibrée du cycle de vie d'un produit en considérant les trois piliers de la durabilité dans une approche unique et éducative. De cette manière, cette publication préparerait les lignes directrices des stratégies dirigées vers la consolidation de l'ADCV. L'ADCV pourrait être utilisée au sein des gouvernements, dans les agences internationales de coopération, ainsi que dans les associations industrielles et de consommateurs. Si nous reconnaissons que la méthode nécessite plus de recherches et d'applications, nous confirmons cependant que l'ADCV est déjà réalisable et encourageons son application, afin d'accélérer la courbe d'apprentissage de la société.Cette publication contient des études de cas qui illustrent comment les pratiques actuelles et émergentes sont utilisées dans le monde entier, de l'Asie en passant par l'Europe, jusqu'en Amérique latine.

Resumen Ejecutivo

En esta introducción al concepto de análisis de la sostenibilidad en el ciclo de vida (ASCV), se reconocen los fundamentos aportados por previos trabajos e iniciativas. Una de ellas es la serie ISO 14040 (Gestión ambiental – Evaluación del Ciclo de Vida – Principios y Marco) que junto a la ISO 26000 (Responsabilidad Social) y la contribución de varias iniciativas internacionales (Apéndice A), han sido esenciales para el desarrollo de esta publicación.

El ciclo de vida de los productos implica flujos materiales, energéticos y monetarios. Sin embargo, el cuadro queda incompleto si no se toman en cuenta los impactos de la producción y el consumo en todos los actores a lo largo de la cadena de valor – trabajadores, comunidades locales, consumidores y la sociedad misma.

Las diferentes técnicas de evaluación permiten a los individuos y a las empresas medir los impactos de sus decisiones de consumo y de sus métodos de producción en las diferentes etapas de la cadena de valor. Así, el análisis de ciclo de vida ambiental (ACV ambiental) observa los impactos potenciales de la extracción de recursos, transporte, producción, reciclaje, uso y desecho de productos, en el ambiente; el costeo de ciclo de vida (CCV) es utilizado para evaluar los costos de dicho ciclo; y el análisis social de ciclo de vida (ACV social) examina las consecuencias sociales de todo este proceso.

Sin embargo, para tener una visión completa es vital expandir el enfoque actual de ciclo de vida para que integre los tres pilares de la sostenibilidad: (i) ambiental, (ii) económico y (iii) social. Esto implica que las evaluaciones basadas en criterios ambientales, económicos y sociales deben realizarse desde una perspectiva global de análisis de la sostenibilidad en el ciclo de vida (ASCV). Esta publicación muestra cómo estas tres técnicas, que comparten objetivos y marcos metodológicos similares, pueden combinarse para avanzar hacia la construcción de un ASCV integral.

Dado su carácter holístico, sistémico y riguroso, el análisis de ciclo de vida (ambiental) es la técnica preferida para compilar y evaluar información relacionada con los potenciales impactos ambientales de un producto. Esta técnica de análisis ha sido estandarizada en ISO 14040 y 14044, y es aplicada por expertos en todo el mundo.

El costeo de ciclo de vida es una técnica para calcular y administrar costos, especialmente en caso de inversiones importantes, y ha sido utilizado por décadas para apoyar a los tomadores de decisiones, a través de un riguroso enfoque de costos privados. Actualmente, diversas investigaciones tratan de definir las condiciones para una mejor alineación del CCV con el ACV (ambiental). Esto ayudará al desarrollo futuro de la técnica de CCV. Debido a su condición de técnica emergente, el ACV social juega un importante rol en la complementación de la información sobre los flujos materiales y energéticos.

Desde fines de la década de 1990, a través de la Iniciativa de Ciclo de Vida, el Programa de las Naciones Unidas para el Medio Ambiente (PNUMA), en asociación con la Sociedad de Toxicología y Química Ambiental (SETAC), ha fortalecido de varias maneras el rol de los enfoques basados en el ciclo de vida. Dos ejemplos son las contribuciones de esta alianza al Proceso de Marrakech sobre Consumo y Producción Sostenible (CPS), y el aporte de varios elementos para el desarrollo del Marco de Programas de 10 años para el CPS (denominado 10YFP, por sus siglas en inglés).

La presente publicación *Hacia el análisis de la sostenibilidad en el ciclo de vida* intenta continuar con dicho trabajo, introduciendo el concepto de análisis de la sostenibilidad en el ciclo de vida (ASCV), para su discusión y debate. De esta manera, se quiere contribuir a las discusiones de la Conferencia de Naciones Unidas sobre el Desarrollo Sostenible en 2012 ('Rio+20').

Igualmente, esta publicación es una contribución a la Iniciativa de Economía Verde del mismo PNUMA, que boga por una economía que mejore el bienestar humano, reduzca desigualdades en el largo plazo, y que no exponga a las generaciones futuras a riesgos ambientales significativos, ni a escaseces de recursos.

Específicamente, *Hacia el análisis de la sostenibilidad en el ciclo de vida* desea concientizar a los tomadores de decisiones sobre la importancia de desarrollar ciclos de vida más sostenibles. Así mismo, intenta apoyar a quienes estén interesados en realizar evaluaciones holísticas de los impactos ambientales y sociales de un producto a lo largo de su ciclo de vida. Finalmente, esta publicación aspira a ofrecer una guía a las empresas y personas que intentan reducir la degradación ambiental y el uso de recursos naturales en sus prácticas de producción, a la vez que aumentar los beneficios ambientales, económicos y sociales para la sociedad y las comunidades locales.

Esta publicación puede ser utilizada como un catalizador para involucrar a las partes interesadas en evaluaciones holísticas y equilibradas de los productos a lo largo de su ciclo de vida, que tengan en cuenta los tres pilares de la sostenibilidad bajo un enfoque único e instructivo. De esta manera, esta publicación proveerá una guía adicional para la consolidación de los ASCV.

El AVSC tiene el potencial para ser usado por los tomadores de decisiones a nivel gubernamental, en agencias de cooperación internacional, en empresas y asociaciones de consumidores. A pesar de que es necesaria mayor investigación, su aplicación no sólo es posible sino también necesaria para incrementar la velocidad de aprendizaje de la sociedad.

Esta publicación contiene ocho estudios de caso que ilustran como las técnicas de ciclo de vida actuales y las emergentes están siendo implementadas alrededor del mundo pasando por Asia, Europa y América Latina.

UNEP Foreword

Nearly 20 years after the Earth Summit, nations are again on the road to Rio, but in a world vastly changed from that of 1992. Then we were just glimpsing some of the challenges emerging across the planet, from climate change and the loss of species to desertification and land degradation. Today, many of those seemingly far-off concerns are becoming a sobering reality, challenging not only our ability to reach the United Nation's Millennium Development Goals but also the very opportunity for close to seven billion people to be able to thrive, let alone survive, in an increasingly crowded world. Rio 1992 did not fail — far from it. It provided the vision and set in place important pieces of the multilateral machinery to achieve a sustainable future.

A transition to a Green Economy is already under way, a point underscored in UNEP's *Green Economy Report* and a growing wealth of companion studies by international organizations, countries, corporations and civil society. But the challenge is clearly to build on this momentum. A Green Economy does not favor one political perspective over another; it is relevant to all economies, be they state or more market-led. Rio+20 offers a real opportunity to scale-up and embed these 'green shoots'.

Along with the debate about corporate responsibility over the past two decades, which led to the ISO 26000 standard on social responsibility and to which UNEP contributed actively, there has been growing demand for direction and guidance on environmental challenges and how to incorporate social and economic issues into sustainability strategies and impact assessments, both in the public and the private sector.

Life cycle assessment, or LCA, is a crucial tool standardized in the ISO 14040 series for changing unsustainable consumption and production patterns. More and more institutional and individual consumers want to understand the world behind the products they buy. They want answers to their questions about products, covering the triple bottom line of sustainability: people, planet, profit. This type of product sustainability information is revealed through life cycle sustainability assessments. Understanding, quantifying and communicating the sustainability of products is part of the solution to continuously reducing their impacts and increasing their benefits to society.

UNEP's Life Cycle Initiative, a collaboration with the Society for Environmental Toxicology and Chemistry (SETAC), has been promoting life cycle management as a key part of the response to the sustainability challenge since 2002. The Life Cycle Initiative has published a number of reference documents since then, such as the *Life Cycle Management Business Guide to Sustainability* and the *Guidelines on Social LCA*. Promoting the complicated tool of Life Cycle Assessment and the holistic concept of Life Cycle Management is no easy task and here I would like to congratulate the Life Cycle Initiative and its experts and partners for bringing to governments, business and civil society an important new piece of work in the sustainability jigsaw puzzle.

Towards a Life Cycle Sustainability Assessment contributes to the 'sustainable development' discussions on the way to Rio+20 by providing techniques to address the three pillars of product sustainability, by combining environmental life cycle assessment, social life cycle assessment and life cycle costing in a coherent framework. With this publication we aim to increase the awareness of decision-makers so that they can make better informed choices for more sustainable products. This implies guiding enterprises and people in their efforts to reduce their environmental footprint, while providing benefits for society. In this way the publication supports a far more intelligent understanding and trajectory towards sustainable development that reflects the needs of a planet that will be home to more than nine billion people by 2050.

Achim Steiner
UN Under-Secretary General and
Executive Director, United Nations Environment Programme

SETAC Foreword

One key objective of the UNEP/SETAC Life Cycle Initiative is to help extend life cycle assessment (LCA) methods and practices beyond their original scope of identifying and characterizing resource consumption and environmental interventions associated with products or processes. LCA can be extended in many ways, but one major development globally has been the creation of methods and techniques that can measure sustainability, allowing LCA to support decision-making toward more sustainable product and process systems. In this way, life cycle techniques can be used to carry out life cycle sustainability assessments. This report shows how.

This guidance document provides a starting-point for learning about the methodologies and techniques suitable for life cycle based ways of measuring sustainability. It describes the three life cycle based techniques and their potential relationship to an integrated life cycle sustainability assessment (LCSA).

Much work remains to be done and we recognize that this report sets out just one of several potential approaches to sustainability assessment. Environmental life cycle assessment (LCA) and life cycle costing (LCC), the economic component of the approach, are quite developed and are well on their way into mainstream business practices. Social LCA – the newest element proposed for this integrated framework – demands caution and requires further development to ensure that the datasets and methods for this new discipline evolve to match those of the more mature components of the overall approach.

Looking ahead, further thought should be given to whether certain elements or activities are essential pieces of the sustainability assessment methodology puzzle. Will a more robust problem definition, a more explicit specification of value-based elements of the assessment and a more systematic framework (such as multi-criteria decision analysis) for organizing indicators and their application to solution alternatives help to complete the puzzle? The UNEP/SETAC Life Cycle Initiative will surely play an important role in answering such questions.

We are confident that this publication will contribute to promoting the development of further life cycle methods and techniques for sustainability assessment. In particular, we hope that concepts and methods will be put forward for an integrated interpretation of indicators in the environmental, economic and social aspects of sustainability decision-making. As this work proceeds and the respective elements are strengthened, we will see notable progress toward consistent and systematic global sustainability assessment.

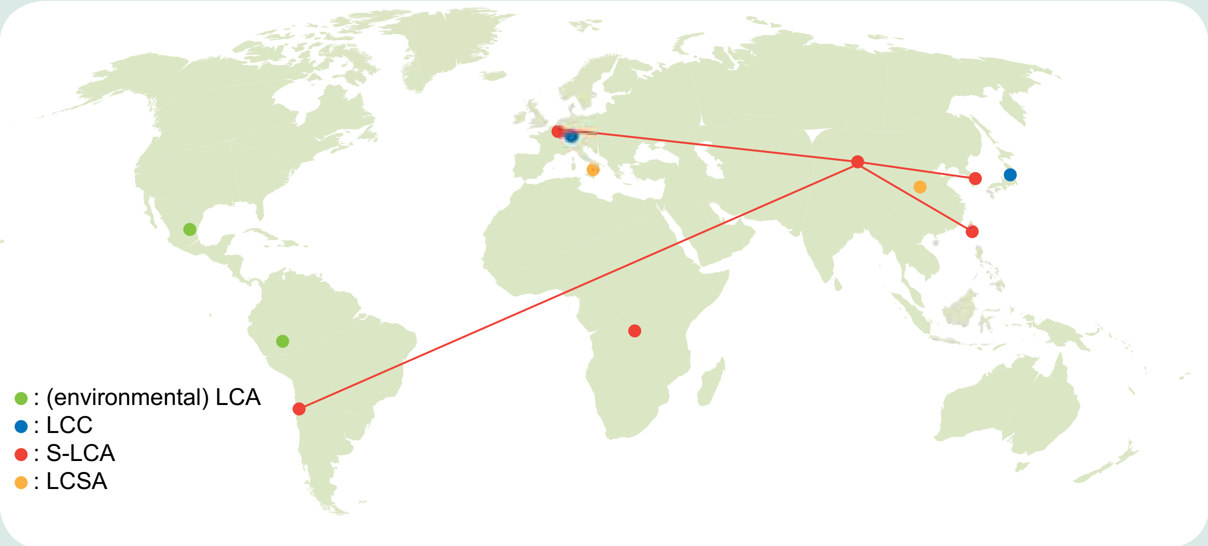
Mike Mozur
Global Executive Director
Society of Environmental Toxicology and Chemistry

Note to Readers

This publication is intended for anybody who would like to know more about different life cycle assessment techniques and their contribution to a combined life cycle sustainability assessment (LCSA).

If you are more familiar with at least one of the three techniques presented, you could skip the introduction (Section 1) as well as the explanation of the specific technique of your domain which is in Section 2. If you know all three techniques, go directly to Section 3 ('LCSA in Practice').

The examples presented in this publication result from an effort to depict the variety of applications worldwide in terms of products analysed, scope and goal, technique applied, findings and users of the results. The products analysed vary from natural-resource extraction through wood products, to energy production and high technology-based products, such as computer notebooks and buses. The cases are meant to highlight the techniques. Readers who would like more detail are encouraged to seek out the original studies. Examples come from the 12 countries depicted in the map below. From the cases presented, it can be inferred that life cycle based techniques can be applied everywhere and for all products, providing useful findings for decision-makers. However, do keep in mind that using only one technique might be very limiting. In line with the aim of the publication, we encourage readers to use the three techniques in combination for an integrated decision-making process towards more sustainable products.



Geographic distribution of the case studies and connections between unit processes included in one S-LCA study

Introduction

1

1.1 Context

This publication shows readers how to use and combine stand-alone life cycle assessment techniques already in use to start an overall life cycle sustainability assessment (LCSA). As (environmental) LCA, LCC and S-LCA are all based on the ISO 14040 (2006) framework and address in a complementary way the three sustainability dimensions (environmental, economic and social), it is possible to integrate these techniques into an overarching life cycle sustainability assessment (LCSA).

In this way, the publication will: (i) help raise awareness among current and future decision-makers in making informed decisions on more sustainable products; (ii) assist stakeholders seeking to make holistic assessments of product life-cycle sustainability, and (iii) support enterprises and people who are trying to reduce environmental degradation, prevent negative social impacts and increase social and economic benefits during the life cycle of a product.

Sustainable development and sustainability are ideas and concepts[1] used with increasing frequency in today's globalized world.

Increasingly, in addition to tackling economic questions when developing policies and strategies, governments and enterprises must consider impacts on the environment and society. There is now growing concern with addressing the *three pillars of sustainability*: (i) environment, (ii) economic, and (iii) social.

The crucial question is: *How do we guarantee more sustainable practices into the future?* Applying *life cycle thinking* (LCT) (also called the life cycle perspective) to the pillars of sustainability offers a way of incorporating sustainable development in decision-making processes. Taking LCT as an approach means going *beyond* the more narrow traditional focus on an enterprise's manufacturing site. LCT also means taking account of the environmental, social and economic impacts of a product over its entire life cycle (from raw material extraction through materials processing, manufacturing, distribution, use, repair and maintenance, and disposal or recycling) and value chain.[2]

1 Within the context of this publication the authors do not distinguish between 'sustainable development' and 'sustainability'. The reference for both is the so-called Brundtland definition.

2 In ISO 26000 'value chain' means the entire sequence of activities or parties that provide or receive value in the form of products or services.

What is sustainability?

The word sustainability stems from the Latin *sub-tenere*, assimilated *sustinere* (to hold up). Since the 1980s the concept has been used in the sense of human sustainability on planet Earth, which has resulted in the most widely quoted definition of sustainability and sustainable development, that of the World Commission on Environment and Development (WCED, Brundtland Commission) of the United Nations (UN) in 1987:

'Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs' (WCED, 1987).

The United Nations Environment Programme (UNEP) and the Society of Environmental Toxicology and Chemistry (SETAC) have used the life cycle approach since the 1990s and through the international 'UNEP/SETAC Life Cycle Initiative' partnership since 2003. Through this initiative, they have contributed to the Marrakech Process on Sustainable Consumption and Production (SCP). The latter was a global multi-stakeholder platform created in 2003 which acted until 2011 to support the implementation of SCP at the regional and national level, and also assisted in the development of a 10-Year Framework of Programmes on SCP, which had been called for in the Johannesburg Plan of Implementation (World Summit on Sustainable Development, 2002). The UNEP/SETAC Life cycle Initiative also contributes to the activities of UNEP's Green Economy Initiative that aims at catalyzing a transition to a low-carbon, high-tech and resource-efficient global economy, using 'beyond GDP' indicators.

The UNEP/SETAC Life Cycle Initiative has three objectives:

1. Enhance the global consensus and relevance of existing and emerging life cycle approaches and methodologies.
2. Facilitate the use of such approaches worldwide by encouraging life cycle thinking in decision-making for enterprises, public authorities and consumers.
3. Expand capability worldwide by applying and improving life cycle approaches.

While the UNEP/SETAC Life Cycle Initiative began with a focus on (environmental) LCA (based on ISO 14040), the initiative moved on to adopt a broader approach towards sustainable development with the aim of converting the existing (environmental) LCA technique 'into a triple-bottom-line sustainable development technique'. Following the publication of the *UNEP/SETAC Guidelines for a Social LCA of Products* (UNEP/SETAC, 2009a) it was proposed that a natural next step would be towards *life cycle sustainability assessment* (LCSA).

This current publication, *Towards a Life Cycle Sustainability Assessment*, facilitates this. It is also anticipated that it will contribute to the 'sustainable development' discussions of the United Nations Conference on Sustainable Development (Summit) in 2012 (named 'Rio+20') by providing techniques to address the three pillars of sustainability of products.

1.2 What is a life cycle sustainability assessment and why take such an approach?

Increasing interest in developing methods to better understand and address the impacts of products along their life cycle has been stimulated by a growing global awareness of the importance of protecting the environment; an acknowledgement of the risks of trade-offs between possible impacts associated with products (both manufactured and consumed); and the necessity of taking account of climate change issues and biodiversity from a holistic perspective.

What is an LCSA?

Life cycle sustainability assessment (LCSA) refers to the evaluation of all environmental, social and economic negative impacts and benefits in decision-making processes towards more sustainable products throughout their life cycle.

1.2.1 What are the benefits of an LCSA?

Potential and future decision-makers, stakeholders, enterprises and consumers can benefit from LCSA in the following ways:

- LCSA enables practitioners to organize complex environmental, economic and social information and data in a structured form.
- LCSA helps in clarifying the trade-offs between the three sustainability pillars, life cycle stages and impacts, products and generations by providing a more comprehensive picture of the positive and negative impacts along the product life cycle.
- LCSA will show enterprises how to become more responsible for their business by taking into account the full spectrum of impacts associated with their products and services.
- LCSA promotes awareness in value chain actors on sustainability issues.
- LCSA supports enterprises and value chain actors in identifying weaknesses and enabling further improvements of a product life cycle. For instance, it supports decision-makers in enterprises in finding more sustainable means of production and in designing more sustainable products.
- LCSA supports decision-makers in prioritizing resources and investing them where there are more chances of positive impacts and less chance of negative ones.
- LCSA helps decision-makers choose sustainable technologies and products.
- LCSA can support consumers in determining which products are not only cost-efficient, eco-efficient or socially responsible, but also more sustainable.
- LCSA stimulates innovation in enterprises and value chain actors.
- LCSA has the potential to inform labelling initiatives.
- Communicating transparent LCSA information helps enterprises to raise their credibility.
- LCSA provides guiding principles to achieve SCP.

1.2.2 How life cycle sustainability assessment is related to the triple bottom line and social responsibility

Elkington (1998) explains that ‘triple bottom line [TBL] accounting attempts to relate the social and environmental impact of an organization’s activities, in a measurable way, to its economic performance in order to show improvement or to make evaluation more in-depth’. In that sense, TBL encourages an

integrated approach of life cycle sustainability assessment, taking into account the three pillars of the environment, economy and society.

Elkington's definition can be seen as similar to the 3P approach: people, planet and profit. While people and planet imply a collective interest, profit can be interpreted as private interest. Therefore, it is not surprising that the World Summit on Sustainable Development (Johannesburg, 2002) referred instead to 'people, planet and prosperity'.

The following international organizations, often recognized for their contribution to the implementation of social responsibility, also address sustainability aspects in enterprises and organizations: UN Global Compact, OECD Guidelines for Multinational Enterprises, ISO 26000 (Guidance on Social Responsibility) and the Global Reporting Initiative (GRI). Often they refer to the importance of the value chain.

In conclusion, life cycle techniques can provide important information for managing 'social responsibility' of an organization and its value chain – from the 'cradle to the grave' – taking into account all dimensions of sustainable development.

2 Life Cycle Techniques

2.1 Life cycle techniques in life cycle sustainability assessment

In order to achieve reliable and robust sustainability assessment results, it is inevitable that the principles of comprehensiveness and life cycle perspectives are applied. The life cycle perspective considers all life cycle stages for products, and for organizations the complete supply or value chains, from raw material extraction and acquisition, through energy and material production and manufacturing, to use and end-of-life treatment and final disposal. Through such a systematic overview and perspective, the unintentional shifting of environmental burdens, economic benefits and social well-being between life cycle stages or individual processes can be identified and possibly avoided. Another important principle is comprehensiveness, because it considers all attributes or aspects of environmental, economic and social performance and interventions. By considering all attributes and aspects within one assessment in a cross-media and multi-dimensional perspective, potential trade-offs can be identified and assessed.

The need to provide a methodological framework for LCSAs and the urgency of addressing increasingly complex systems are acknowledged globally. Some examples of these approaches are presented in Annex A. Stand-alone LCA techniques described in this publication conform to ISO 14040 (2006) and ISO 14044 (2006) which provide the standardized procedural framework of assessment studies.

While using (environmental) LCA to measure the environmental dimension of sustainability is widespread, similar approaches for the economic (LCC) and the social (S-LCA) dimensions of sustainability have still limited application worldwide. These developments are crucial, because they allow for the emergence of life cycle based sustainability assessments. As they have similar perspectives and aims and because they are all based on the ISO 14040 (2006) stages (Phases 1, 2, 3 and 4), it is possible to combine these techniques into an overarching LCSA. Walter Klöpffer put this idea into a conceptual formula (Klöpffer 2008, Finkbeiner et al., 2010) when he suggested the *combining of the three techniques*. Klöpffer's 2008 formula underlines the importance of reading the results of each technique in combination with the results of the other techniques rather than summing them up; this will allow for integrated decision-making based on a life cycle perspective and the consideration of the three sustainability dimensions:

LCSA = (environmental) *LCA* + *LCC* + *S-LCA*[3]

(from Klöpffer [2008] and Finkbeiner et al. [2008])

Combining (environmental) LCA, S-LCA and LCC contributes to an assessment of products, providing more relevant results in the context of sustainability. The following sections describe these techniques and their evolution in more detail.

2.2 (Environmental) life cycle assessment

The concepts that later became (environmental) LCA first emerged in the 1960s (Baumann et al., 2004). Until the early 1990s, studies that undertook an assessment of the material, energy and waste flows of a product's life cycle were conducted under a variety of names – including the resource and environmental profile analysis (REPA), ecobalance, integral environmental analyses and environmental profiles. In 1990, SETAC hosted workshops with the aim of developing a standardized method of (environmental) LCA, which was to serve as the basis for the ISO 14040 series. Several guidelines have been published by SETAC since then (see References section).

3 Where LCSA is life cycle sustainability assessment; LCA is environmental life cycle assessment; LCC is life cycle costing; S-LCA is social life cycle assessment.

The ISO 14040 series provides a technically rigorous framework for carrying out (environmental) LCAs. It has also been adopted for S-LCAs and LCCs and the technique has been accepted overall by the international community. Since the release of the 14040 series, a rapidly growing number of (environmental) LCA studies have been published. While the methodology for (environmental) LCA has developed and matured over the last decades, there are still several fields that need attention. These include methods for assessing impacts on ecosystem services from land use and impacts from water use, valuation methods, uncertainty assessment methods and consistency, quality assurance of (environmental) LCA databases, the field of consequential LCA, hybrid approaches combining input-output (IO) and LCA, etc.

In recent years, increasing awareness in the general public, industry and governments has raised the concept of integrating (environmental) LCA into management systems, and using it in environmental policy-making because (environmental) LCAs can assist in communicating environmental issues in a balanced way. LCA is also increasingly accepted as a technique by organizations to inform strategic decision-making.

Globally, many countries are developing strategies that promote life cycle thinking based on lessons learned from (environmental) LCAs. One example is the concept of integrated product policy (IPP) as communicated by the European Union.

In addition, findings from (environmental) LCAs are increasingly being communicated to consumers through tools such as eco-labels as an easy guide to identify more environmentally friendly products. These ecolabels have been recognized for several sectors as a significant interface between production and consumption patterns (UNEP, 2007). Recent years have also shown a sharp increase in the development of environmental product declarations (EPDs).

2.2.1 What is (environmental) LCA and how is it applied?

In summary, (environmental) LCA is a technique that is used to assess the environmental aspects associated with a product over its life cycle. As established in the ISO 14040 and 14044 standards, an (environmental) LCA is carried out in four phases, which are normally interdependent:

1. Goal and scope.
2. Inventory of resources use and emissions.
3. Impact assessment.
4. Interpretation.

These are described in more detail below.

Phase 1 State goal and scope of study

First, the goal and scope of the study must be stated explicitly. This provides the context for the assessment and explains *to whom* and *how* the results are to be communicated. This step includes the detailing of technical information – such as defining the *functional unit*, the *system boundaries*, the *assumptions* and the *(de)limitations* of the study, the *impact categories* and the *methods* that will be used to allocate environmental burdens in cases where there is more than one product or function.

Phase 2 Inventory of resources and emissions

In the second phase, all emissions released into the environment and resources extracted from the environment along the whole life cycle of a product are grouped in an inventory. The inventory is a list of elementary flows as shown in Fig. 1.

Phase 3 Life cycle impact assessment: Translate results into environmental impacts

In the third phase – life cycle impact assessment (LCIA) – the LCI results or indicators of environmental interventions are translated, with the help of an impact assessment method, into environmental impacts. Impacts may be assessed at the midpoint or endpoint level (see Fig. 2). In a

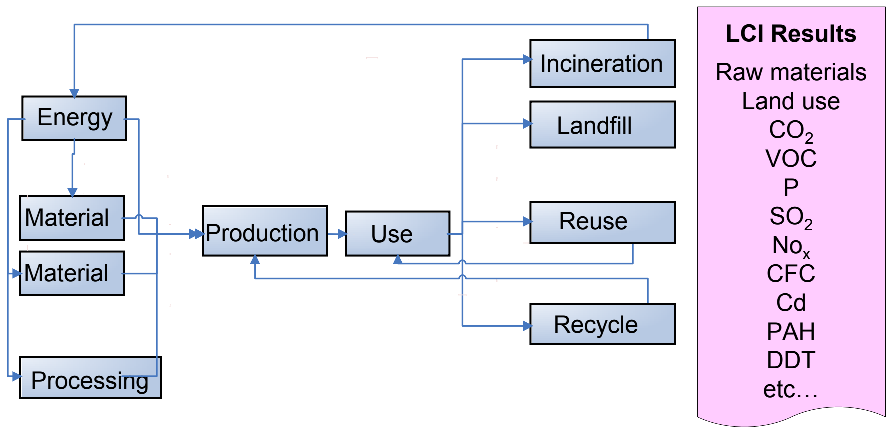


Figure 1. Flows of information needed for a life cycle inventory.

'classification' step, elementary flows[4] are assigned to midpoint impact categories such as 'climate change' or 'human toxicity', thereby organizing the information to allow for a further processing and meaningful interpretation (see Fig. 2 below). In this ISO 14040-termed 'characterization' step, all elementary flows within the same category are converted to a common unit of assigned elementary flows. This step is accomplished by using characterization factors (see Glossary).

At the endpoint, environmental LCIA aims to link emissions and resource demands with damages to human health, ecosystem quality and the resource base. Several characterization models can be used to link the inventory results with the midpoint and endpoint categories of impact: the choice of model depends on the goal and scope of the study and on the stakeholders affected by the outcome.

Normalization, aggregation and *weighting* are optional LCIA steps, according to ISO 14040 (2006) and ISO 14044 (2006). While the first provides the contribution of each impact category in comparison to a reference[5] by converting differing units into a common and dimensionless format,[6] aggregation and weighting allow the conversion (using numerical factors based on value-choices) and the possible aggregation of indicator results across impact categories.

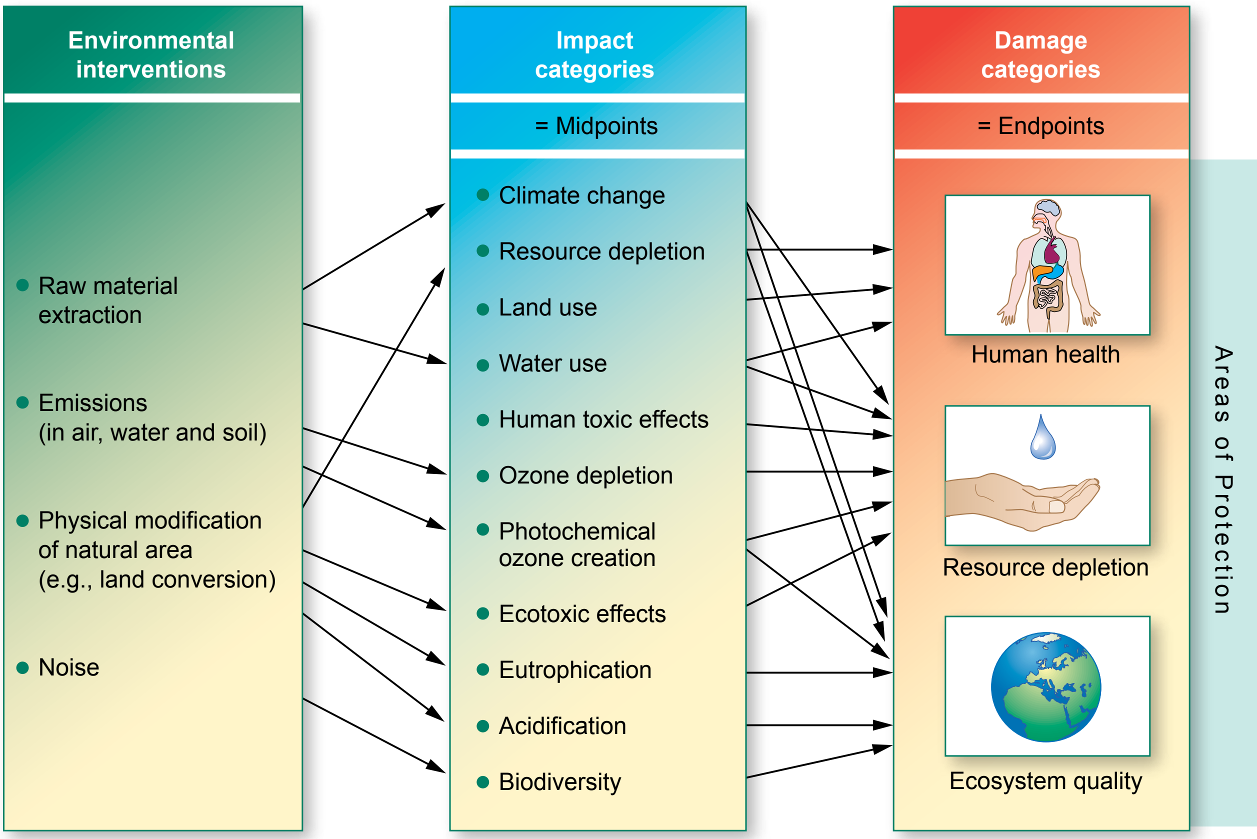


Figure 2. Overall UNEP/SETAC scheme of the environmental LCIA framework, linking LCI results via the midpoint categories to damage categories (adapted from Jolliet et al., 2003a).

4 See the definition in the Glossary.

5 Reference is chosen by the practitioner. A common reference is the impact caused by a citizen in one year.

6 This can be done by dividing indicator values by a reference quantity.

Phase 4 Interpretation

A life cycle interpretation is carried out in the last phase. This is necessary for identifying, quantifying, checking and evaluating information from the results of the LCI and/or the LCIA. This interpretation phase should generate a set of conclusions and recommendations. It should also (according to ISO 14040) raise significant environmental issues, including an evaluation of the study considering completeness, sensitivity and consistency checks; and limitations.

To comply with ISO 14040 (2006) and ISO 14044 (2006) standards, a critical review (CR) is mandatory for (environmental) LCAs *where results are made available to the public*. A CR panel for reviewing an LCA study should be composed of at least three experts (independent consultants or members of external independent bodies). An external independent expert is selected by the original commissioner to act as chairperson of the panel. Based on the goal, scope and budget available for the review, the chairperson may select further independent qualified reviewers.

In cases of *non-comparative* (environmental) LCA studies or assertions based on such studies, the CR is voluntary and can be performed in principle by one or two independent experts (e.g. an LCA expert and a data/technology expert). The costs depend on the size of the study, the quality of and amount of data available, among other factors.

CASE STUDY
(Environmental) life cycle assessment of a wooden product in Mexico

Phase 1 Goal and scope

In 2008 Gonzalez et al. carried out an LCA on Mexican school desks. They looked at the wooden furniture supply chain in order to determine how the Mexican wooden furniture industry impacts on the natural environment. The LCA was used to: evaluate the potential environmental impacts of the school desk; provide information on areas to improve the desk; and promote the use of certified wood.

The product's life cycle stages studied were: the harvesting of Forest Stewardship Council (FSC) certified wood; transportation of the wood; cutting of the logs into boards; the manufacture of the boards into school desks; the distribution of the desks to the schools; and the use of discarded desks as fuel in an industrial boiler.

Assumptions

The results were also normalized according to 1995 global values to estimate and evaluate the relative scale of the various impact categories over the desk's life cycle. The highest contribution was set to 100% and all other impact categories are expressed relative to that contribution.

Phase 2 Life cycle inventory

A life cycle inventory (LCI) analysis identified and quantified the inputs and outputs (the product, emissions to air, water and soil, as well as solid waste) in each stage of the life cycle. Input and output data for the production of the quantity of one desk were tabulated for the processes in the desk's life cycle. Data were then modelled into inputs and outputs in process inventory data tables. The environmental burdens for some processes were determined by economic allocation. In accordance with ISO 14040 (2006) and 14044 (2006), economic allocation was used for processes that deliver two or more coproducts, provided that each of them has an economic value.

Table 1. Input/output table for wooden school desk (Gonzalez et al., 2008)

Stage	Process	Category	Inputs	Amount	Unit	Data Source
PRODUCTION	Raw wood	Materials	Included in the next step: wood from yellow pine			Authors
	Sawmill process	Materials	Log from yellow pine	2.11E+01	kg	Authors
			Phenol for wood treatment	1.53E-06	kg	Ecoinvent*
		Water	Tap water	3.41E-02	kg	Ecoinvent*
		Energy	Electricity	1.40E-01	kWh	Authors
			Diesel	4.98E-03	lt	Authors
			Lubricant oil	7.66E-04	lt	Ecoinvent*
			Ethylene Glycol	1.70E-05	lt	Ecoinvent*
			Gasoline	4.98E-03	lt	Authors
	Dry boards process	Materials	Sawn wood	1.37E+01	kg	Authors
			Saw dust	1.50E+00	kg	Authors
		Water	Tap water	9.80E-01	m^3	Ecoinvent*
		Energy	Electricity	7.94E+01	kWh	Authors
			Diesel	1.76E+00	lt	Authors
			Gasoline	1.76E+00	lt	Authors
	School furniture	Materials	Sawn kiln dried boards	1.36E+01	kg	Authors
			Sealer polyurethane	3.40E-01	kg	Authors
			Lacquer polyurethane	3.40E-01	kg	Authors
			Sealer and Lacquer cans from aluminium	4.00E-02	kg	Authors
			Screws, galvanized	4.00E-01	kg	Authors
		Energy	Electricity	8.57E+00	kWh	Authors
TRANSPORTATION			Of sawn wood in the sawmill process (28 tonne truck)	843	kgkm	Ecoinvent*
			Of sawn wood in the drying process (16 tonne truck)	15	kgkm	Ecoinvent*
			Of school desks to the city (16 tonne truck)	570	kgkm	Ecoinvent*
			Of school desks to the school (16 tonne truck)	190	kgkm	Ecoinvent*
FINAL DISPOSAL (Energy recovery)		Transportation	Of waste to the final disposal (16 tonne truck)	380	kgkm	Ecoinvent*

*http://www.ecoinvent.ch/

**More than 400 emissions to air and water had been quantified; however, for the purposes of this publication they are not listed here but summarized in Table 2 and Fig. 3.

*** HTP: Human toxicity potential; FAETP: Freshwater aquatic ecotoxicity potential; TETP: Terrestrial ecotoxicity potential.

Outputs				Economic Allocation
Products	Tree logs per truck load	550.3	kg	
Products	Sawn wood	1.37E+01	kg	80%
By products	Sawdust	7.40E+00	kg	20%
Emissions to water and air	**			
Products	Sawn Kiln Dried Wood Boards	1.36E+01	kg	
Solid waste	Lubricants	2.69E-04	lt	
Emissions to water and air	**			
Products	School desk (1 piece)	9.50E+00	kg	95%
By-products	Sawdust	4.10E+00	kg	5%
Emissions to water and air	**			
Emissions to water and air (potential impacts after classification and characterization)	CO_2 eq	3.43E-01	kg	
	CFC-11 eq	4.70E-08	kg	
	1,4-DCB eq (HTP***)	4.62E-03	kg	
	1,4-DCB eq (FAETP***)	2.63E-03	kg	
	1,4-DCB eq (TETP***)	1.89E-04	kg	
	C_2H_4 eq	6.42E-05	kg	
	SO_2 eq	1.88E-03	kg	
	PO_4--- eq	3.94E-04	kg	
Waste disposal	One piece of furniture	9.50E+00	kg	100%
Avoided resource use	Natural gas	2.57E+00	m^3	
By-products	steam			

Phase 3 Life cycle impact assessment

The study applied the LCA accounting convention that carbon dioxide, carbon monoxide and other global warming gases resulting from the combustion of the used chairs contain biogenic carbon. Therefore, the values of global-warming impacts of these biogenic emissions were converted to zero.[7]

Characterization (environmental profile) results of the FSC certified wooden school desk indicated different contributions of different life cycle stages of the desk. Smaller inputs were combined for clarity. For example, Table 2 below presents the characterized impacts in the nine different units of the impact categories of the CML 2001[8] method. Oil used in the machines that felled the trees is listed first, followed by a column that combines other inputs for the sawing of the boards. The totals of these impacts are then multiplied by an 80% economic allocation factor for the portion of boards that are not converted to sawdust waste.

To compare the relative scale of each of the impacts created by production of the school desk in each of the impact categories, each impact category was divided by the CML Baseline 2001 estimated category totals for each category (according to 1995 global estimates). A normalization with the largest value leads to the dimensionless side-by-side presentation in Fig.3.

7 Since bioenergy carbon does not add new carbon to the carbon cycle the impacts can be considered as zero.

8 CML (Guinée et al., 2002) is an impact assessment method, which restricts quantitative modelling to relatively early stages in the cause-effect chain to limit uncertainties and groups LCI results in so-called midpoint categories, according to themes. These themes are common mechanisms (e.g. climate change) or commonly accepted groupings (e.g. ecotoxicity). For more information, please see: www.cml.leiden.edu/research/industrialecology/researchprojects/finished/new-dutch-lca-guide.html#the-handbook

Table 2. Potential life cycle impacts table for wooden school desk – wood extraction and board sawing (Gonzalez et al., 2008).

CML Impact category	Units	Oil for tree felling	Other board sawing inputs	Total for 21.08 kg boards	Allocation factor	13.7 kg boards
Abiotic depletion	kg Sb eq	6.67E-02	4.03E-02	1.07E-01	8.00E-01	8.56E-02
Global warming	kg CO_2 eq	1.23E+01	5.56E+00	1.79E+01	8.00E-01	1.43E+01
Ozone layer depletion	kg CFC-11 eq	0.00E+00	0.00E+00	0.00E+00	8.00E-01	0.00E+00
Human toxicity	kg 1,4-DCB eq	5.15E-02	1.58E+00	1.64E+00	8.00E-01	1.31E+00
Fresh water toxicity	kg 1,4-DCB eq	0.00E+00	2.62E-01	2.62E-01	8.00E-01	2.10E-01
Terrestrial toxicity	kg 1,4-DCB eq	0.00E+00	2.40E-02	2.40E-02	8.00E-01	1.92E-02
Photochemical oxidation	kg C_2H_4	5.47E-03	3.54E-03	9.00E-03	8.00E-01	7.20E-03
Acidification	kg SO_2 eq	1.52E-01	3.35E-02	1.85E-01	8.00E-01	1.48E-01
Eutrophication	kg PO_4 eq	4.38E-03	7.62E-03	1.20E-02	8.00E-01	9.60E-03

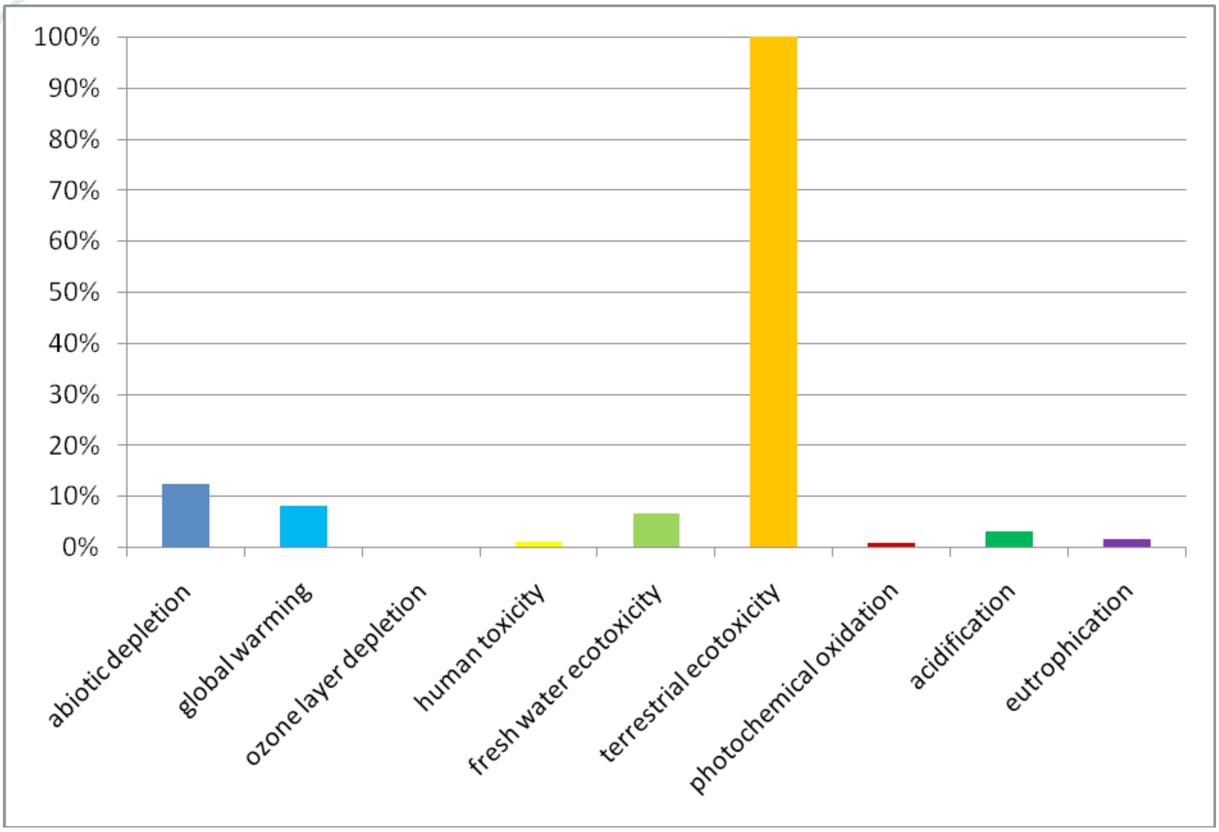


Figure 3. Normalized results per impact category of a school desk made from FSC certified wood (based on data from Gonzalez et al., 2008).

Phase 4 interpretation

The highest normalized value occurs in the impact category terrestrial ecotoxicity. Regarding the other impact categories, their potential contribution on a global scale are lower, with abiotic depletion, global warming and fresh water ecotoxicity ranging from 12% to 7%. Other categories have discernible yet minor potential impacts. *The magnitude of the columns refers only to the normalized value.* When an overall interpretation of the results is conducted, all categories must be taken into account.

Conclusions

This assessment identified environmental impacts associated with the production of FSC certified wooden furniture that is manufactured, used and disposed of in Mexico. Inventory results indicated that board drying is the step with the highest consumption of electricity and offers the greatest opportunities for improvements in environmental performance. Future assessments could more thoroughly document various aspects of the desk's life cycle, including modelling the transport of the metal cans, the use of the sawdust waste and the transport of used screws to a recycling centre following incineration of the wood.

Strategies to potentially improve the environmental performance of the desk include, among others, exploring methods to cut and dry the boards with lower (or no) fossil fuel consumption, identifying ways to use the waste sawdust and redesigning the desk to make it last more than eight years.

CASE STUDY

(Environmental) Life cycle inventory of gold in Peru

Phase 1 Goal and scope

The goal of the study (Valdivia and Ugaya, 2011) was to evaluate the environmental impacts of gold produced through artisanal and small-scale mining activities (A&Sma) in Peru. The functional unit used was 'the production of 1 kg of gold'. The product system consisted of the following unit processes: excavation; the initial separation of the material; amalgamation; the second separation of the material; gold concentration; mercury recovery; electricity generation and transportation.

The case study was performed in Mazuco, an Amazon rainforest area in Peru, which produced 43.2 kg of gold (99.5% purity) in 2005.

Phase 2 Life cycle inventory

Figure 4 gives the results of the life cycle inventory. Mercury emissions to air and soil amount to 60 and 140 grams, correspondingly, while CO_2 emissions accounted for 20,223 kg. The natural rainforest area that was transformed was 373 m^2 and fresh water from natural watersheds used amounted to 49,019 tonnes.

Phase 4 Interpretation

The Peru case study covered Phases 1, 2 and 4 of an (environmental) LCA. The authors concluded that the processes of concentration, amalgamation and recovery were responsible for the emissions of mercury. The consumption of most natural resources occurred in the excavation and extraction stages, as well as the air emission (e.g. CO_2) and soil pollution. No water scarcity was registered for this area. However, considering the fragility of the natural area affected, issues of land transformation and soil and water pollution from mercury might be relevant for further research.

2.3. Life cycle costing

Life cycle costing (LCC) is the oldest of the three life cycle techniques. Developed originally from a strict financial cost accounting perspective, in recent years LCC has gained importance. The origins of LCC go back to 1933, when the United States of America General Accounting Office (GAO) requested an assessment of the costs of tractors that considered a life cycle perspective in a Request for Tender. Today, different 'flavours' of LCC exist for different industrial sectors and products. Figure 5 highlights three of these flavours:

1 Conventional LCC incorporates private costs and benefits (the areas included within the blue line in Fig. 5).

2 Life cycle costing (LCC)[9] also takes into account external relevant costs and benefits anticipated to be privatized (the areas included within the red line in Fig. 5). For example, if it is expected in the future that a new tax on CO_2 will be enforced or a subsidy granted for engaging unskilled people within the next two years, the LCC (within red lines in Fig. 5) will reflect these costs and benefits in its calculations.

3 A third approach is the so-called 'societal LCC' (the areas included within the green line in Fig. 5) in which all private and external costs and benefits are monetized.

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9 Hunkeler et al. (2008) call this 'environmental LCC'.

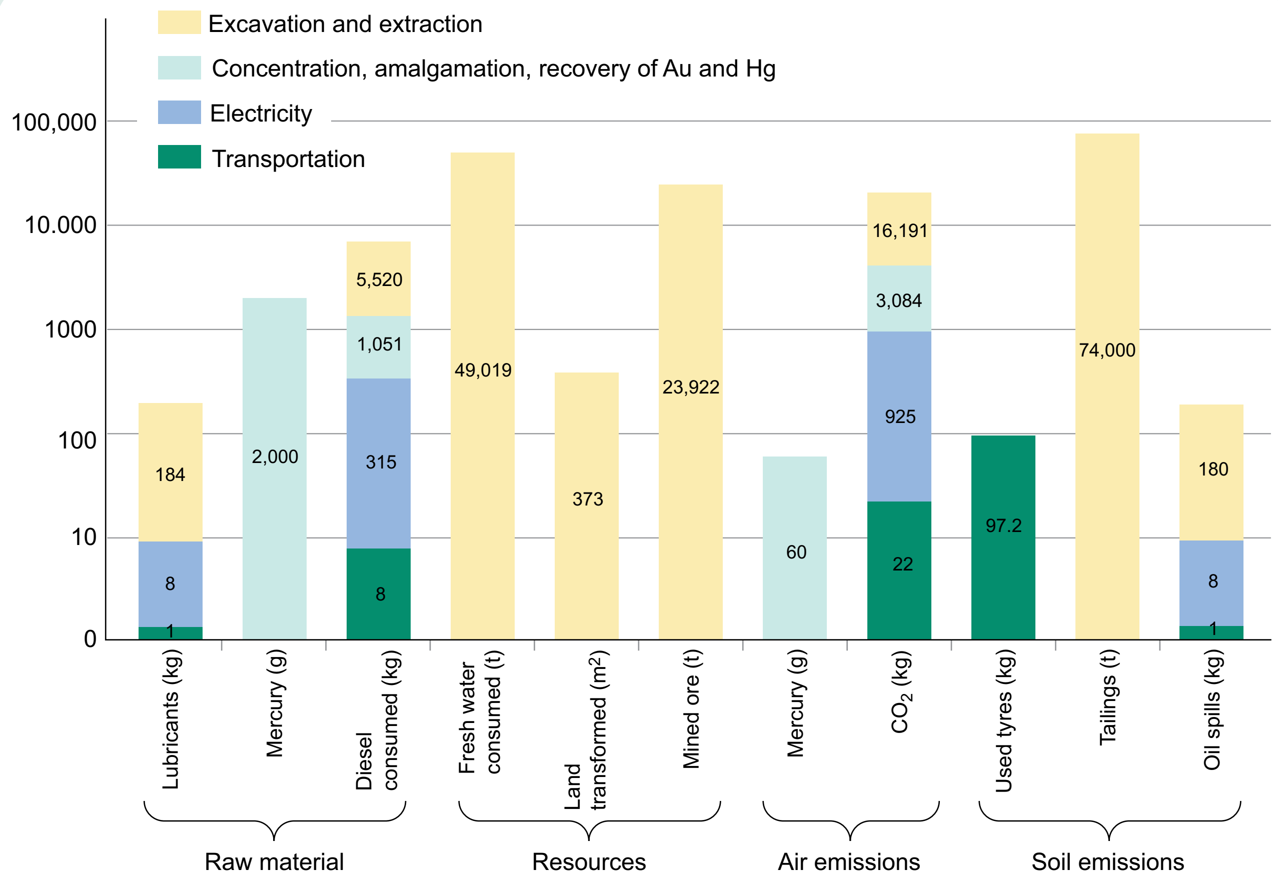

Figure 4. Life cycle inventory (LCI) of 1 kg of gold (99.5%) (Valdivia and Ugaya, 2011).

A scientific working group on LCC within SETAC, running from 2002 until 2007, was the first to specify an LCC methodology (Hunkeler et al., 2008) that aimed to provide an assessment of the costs of a product across its entire life cycle consistent to an (environmental) LCA. This work was the basis for the published guidelines describing the method and a code of practice (Swarr et al., 2011b).

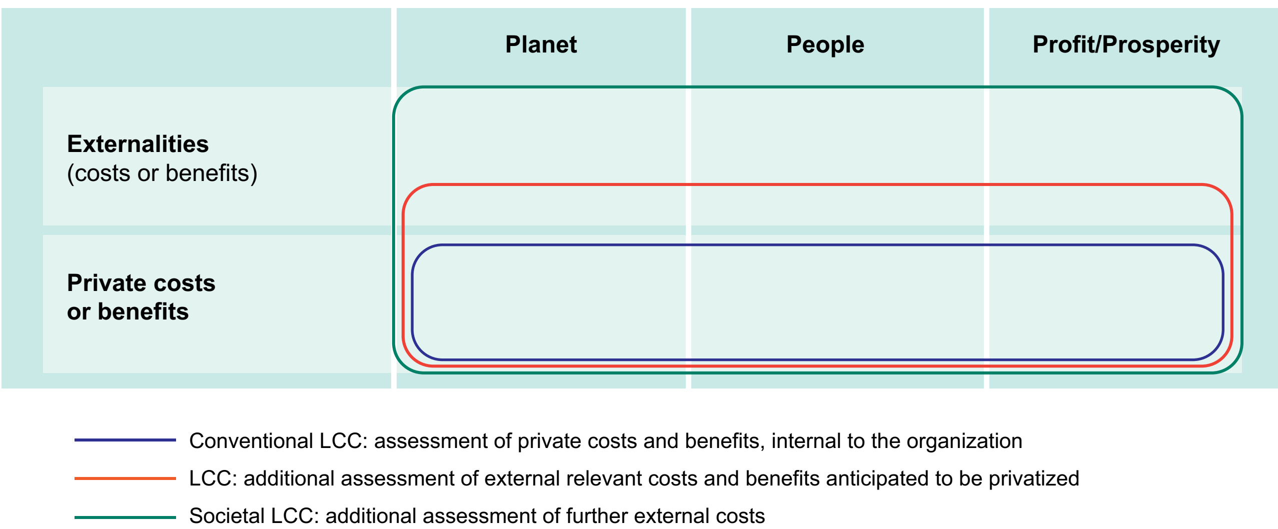

Figure 5. Scope of application of three flavours of life cycle costing.

Swarr et al. (2011b) acknowledge that 'it will be important to apply these guidelines to additional case studies to gain experience and validate the utility of the method across different industry sectors. Some experimentation is required to show how complementary LCC and LCA studies can effectively inform decision-making of multiple stakeholders with differing and potentially conflicting perspectives and goals.

Since LCC has been promoted as one of three sustainability pillars, there is a need to explore how this technique can be linked to the economic pillar of sustainability. In industrialized countries, there is a growing demand for LCC – from both public procurement departments and private sectors. In addition, LCC can be applied to assess the full costing of long-life goods (i.e. building objects, infrastructure, railways, trains and aviation projects) which imply a long-term maintenance and use phase as well as high costs.

Life cycle costing is extremely useful for monitoring costs under different scenarios, making it attractive to the product's clients and the financial sector. Through UNEP's programme on Sustainable Procurement, emerging economies and developing countries are starting to exercise and test the incorporation of this concept in their public procurement activities.

2.3.1 What is life cycle costing and how is it applied?

Basically, LCC in this publication is an aggregation of all costs that are directly related to a product over its entire life cycle – from resource extraction over the supply chain to use and disposal. It also takes into account external relevant costs and benefits anticipated to be privatized (as depicted by the areas within the red line in Fig. 5 above). It is usually carried out in four phases:

1 Define a goal, scope and functional unit.

2 Inventory costs.

3 Aggregate costs by cost categories.

4 Interpret results.

Phase 1 Define a goal, scope and functional unit

Following ISO 14040, in Phase 1, an LCC will *define the goal of the study, a functional unit*, *specify system boundaries*, *apply allocation procedures*, *discount rates* and so forth. It is also important to state the *viewpoint of the life cycle actor* (whether supplier, manufacturer, user or consumer) during this phase. At this stage also, a cost breakdown structure (CBS) should be developed in order to facilitate the consistent collection of data along the full life cycle and which can also be aggregated along the life cycle.

A discount rate can be important – especially for durable goods with cost flows in the future. In principle, the motivation for applying a discount rate seems valid – converting future costs into a present value for current decision-making. However, there is no consensus on criteria about which discount rate should be applied for an LCC. Therefore, a sensitivity analysis for different discount rates is recommended; applying a discount rate of 0% would mean that no discounting is used.

An LCC is always conducted for a certain function that must be fulfilled by the analysed system. This function is quantified by the *functional unit*, which provides a reference to which all costs and benefits are then related.

Phase 2 Inventory costs

In Phase 2, costs are *inventoried on a unit process level*. The level of aggregation may vary significantly over the life cycle and between different unit processes. Since more than one product is produced by most enterprises, the allocation of costs to each product is required. For example, in the case of two metals produced at the same time, overhead costs can be distributed to each metal proportionally to the incomes received by each metal, or the number of working hours implied by the metal production, among others.

Phase 3 Aggregate costs by cost categories

In Phase 3, the obtained costs are aggregated by cost categories. The definition of cost categories and the development of the inventory are especially difficult along supply chains. It will help to have a better understanding of the costing systems in the countries or regions where the suppliers are based. For details, see Ciroth (2008).

Phase 4 Interpret results

The interpretation of results (in this case, resulting costs) is the final step. A review may follow, although it is not yet common (Hunkeler et al., 2010). Figure 6 depicts the three dimensions of costs relevant for LCC: (i) the life cycle stage (e.g. design and development) versus (ii) the cost category (e.g. labour costs) versus (iii) the product work/breakdown structure (i.e. power supply).

For LCC, areas for future needs of research and development include the definition of cost categories, data availability and data quality assessment and assurance.

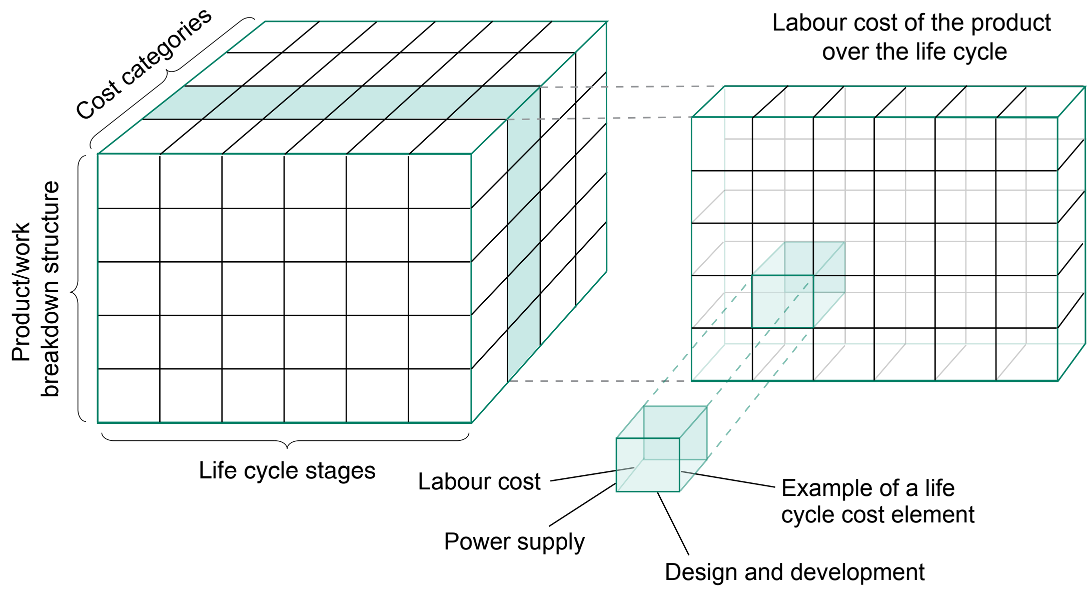

Figure 6. Cost categories and the share of labour costs in life cycle costing (IEC, 1996)

CASE STUDY

Life cycle costs of standard public transport heavy duty buses

Phase 1 Define goal, scope and functional unit

In the context of a study commissioned by the European Commission in 2007, LCC calculations of 11 different product groups for different European member states were carried out (see Rüdenauer et al., 2007). The goal of the studies was to compare, for each product group, the LCC results of two versions. While one version implied high investment costs and lower resource demand, the other version presented opposite characteristics.

An LCC carried out on two versions of standard public transport heavy duty buses provides an interesting example of LCC calculations. Version 1 was a conventional EURO 4 bus and Version 2 a compressed natural gas (CNG) driven bus: both buses had the capacity to hold up to 80 passengers.

In LCC the system boundaries include a clarification on the geographical scope and the period of data collection. In this case, the geographical coverage was Germany, so that only cost data representative for German purchasing authorities was used. In terms of time-related coverage, only cost data not older than two years was used.

The LCCs were calculated for the whole assumed holding period of 10 years with an annual vehicle mileage of 60,000 km, amounting to a total fuel consumption of 600,000 km within the assumed holding period, which served as the functional unit for both versions.

Phase 2 Inventory costs

The relevant cost elements considered for the LCC of standard public transport heavy-duty buses were investment costs, VAT, motor vehicle tax, fuel costs, maintenance costs and costs for end-of-life disposal (in this case, resale value).

The fuel prices over the chosen holding period were increased with the (then) valid inflation rate of Germany (2.0% in March 2007). All future costs were discounted to give the net present value (NPV), using a discount rate (4.4%) derived from the long-term interest rates of the selected member states for which the analysis was conducted.

Phase 3 Aggregate costs by cost categories

Table 3 and Fig. 7 give the results of the LCC of the two versions of standard public transport buses in Germany.

Phase 4 Interpret results

In the case of Version 1, with less investment costs, the fuel costs were much higher than in the case of Version 2. This influenced substantially the total results of the LCC of Version 1.

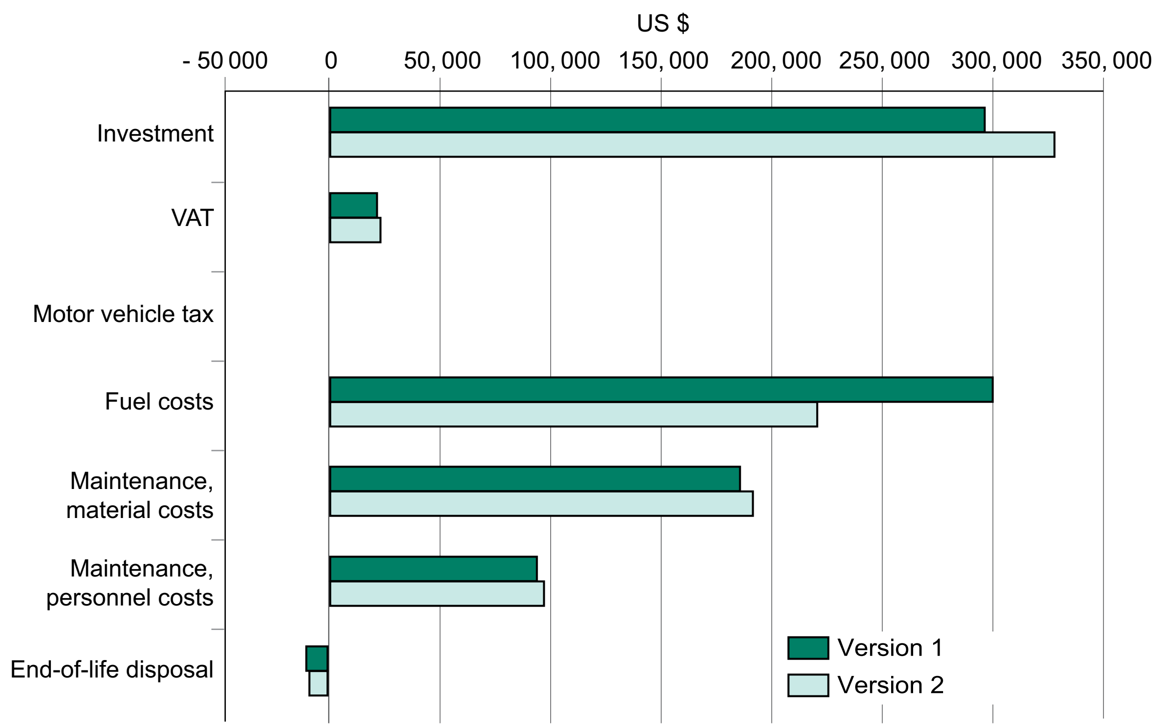

Figure 7. LCC of standard public transport heavy duty bus (in US$) (adapted from Ruedenauer et al. 2007).

Table 3. Costs of standard public transport heavy duty bus (Ruedenauer et al., 2007).

	Version 1 (US$)	Version 2 (US$)
Investment (US$)	295,544	328,826
VAT (US$)	20,688	23,018
Motor vehicle tax (US$)	0	0
Fuel costs (US$)	299,451	220,155
Maintenance, material costs (US$)	185,085	190,457
Maintenance, personnel costs (US$)	92,543	95,228
End-of-life disposal (US$)	-8,655	-8,655
Total net present value (US$)	**884,657**	**849,029**

Legend: Version 1: Conventional EURO 4 bus; Version 2: CNG driven bus.

Conclusions

Even though the CNG driven bus (Version 2) was more expensive in terms of investment costs by approximately 11%, the LCC was slightly lower (4%). This was mainly due to the lower fuel costs, which are subsidized in Germany through lower taxes.

CASE STUDY

Life cycle costs of a washing machine with water recirculation

Phase 1 Goal and scope and system boundaries

According to Yamaguchi et al. (2006, 2007a and 2007b), the goal of this study was to evaluate the full cost (including external costs) of two versions of washing machines using LCC. The first washing machine represents an old version with no recirculation of water and the second version includes a recirculation option and, hence, less water consumption in the washing drum. Yamaguchi et al. explain that the functional unit refers to the *operation of a washing machine being used 535 times per year and washing of 8 kg laundry each time* (this was based on a survey carried out by the Japanese Detergent Society). The water and electricity consumption in both versions behave differently. The washing machine with water recirculation achieves savings of 90 litres and consumes more electricity (i.e. additional 35W during 25 minutes [or 0.145 kWh] for one washing). The standard water consumption of the first washing machine is 190 litres of water per washing. To accomplish the LCCs of both versions the following life cycle stages were investigated: planning, development and commercialization, manufacturing, transportation, sales, distribution, use and end-of-life. In order to allow comparisons, the same amount of the detergent used was assumed for both washing machines.

Phases 2 and 3 Inventory costs and aggregate costs by cost categories

LCC data were mainly collected from the accounting section of the washing machine company. Data about the use stage were collected by means of questionnaires filled in by consumers of this product. The social (external) costs were calculated by means of the LIME tool and based on the inventory data of both versions of washing machines. The LIME tool calculates the social costs by statistical valuation techniques that estimate first converting the endpoint damages to Japanese yens; this can be done by statistical valuation techniques that estimate consumers' willingness to pay. Afterwards, the LIME technique weights the results and produces a single figure. Finally, the private costs and the social (external) costs are summed to provide the full cost assessment.

Phase 4 Interpret results

Table 4 presents the costs resulting for each life cycle stage of both versions of washing machines which are the basis for Fig. 8. In case of the second version of the washing machine (Version 2), the costs of the planning, research and development and manufacturing activities increased by adding the water circulation pump unit, but the water use-related costs notably decreased. Social costs estimated by the LIME tool evaluation module also decreased in Version 2 although this reduction is not significant compared to the decrease of the full cost (LCC plus social cost) of 23.5% of the Version 2 washing machine.

Conclusions

This case study shows that the social cost calculated by LIME, which is based on the methodology of (environmental) LCA, is very small, i.e., around 3% of the total LCC. However, it should be highlighted that Version 2 decreases 31.6% of the social cost of Version 1. In sum, interpretation of results should recognize that LIME is limited in its capacity to consider a wide range of social costs. Therefore, social costs are understated relative to environmental costs.

Table 4: Full cost accounting for washing machines before and after dewatering and water recirculation (Yamaguchi et al., 2006, 2007a and 2007b).

Life cycle stage	Water consumed (no recirculation applied): Version 1 (% of full cost)	Water consumed following a dewatering and recirculation process: Version 2 (% of full cost)
Planning, research and development	0.50	1.00
Manufacturing	7.62	11.01
Transportation	0.38	0.44
Sales	2.36	4.13
Head and group offices	1.36	1.94
Distribution	5.12	5.38
Use: Electricity	4.11	4.44
Use: Tap water	29.88	13.57
Use: Sewage system	23.25	10.44
Use: Detergent	21.37	21.14
End-of-life	0.31	0.50
Social cost	3.74	2.56
Total	100.00	76.55

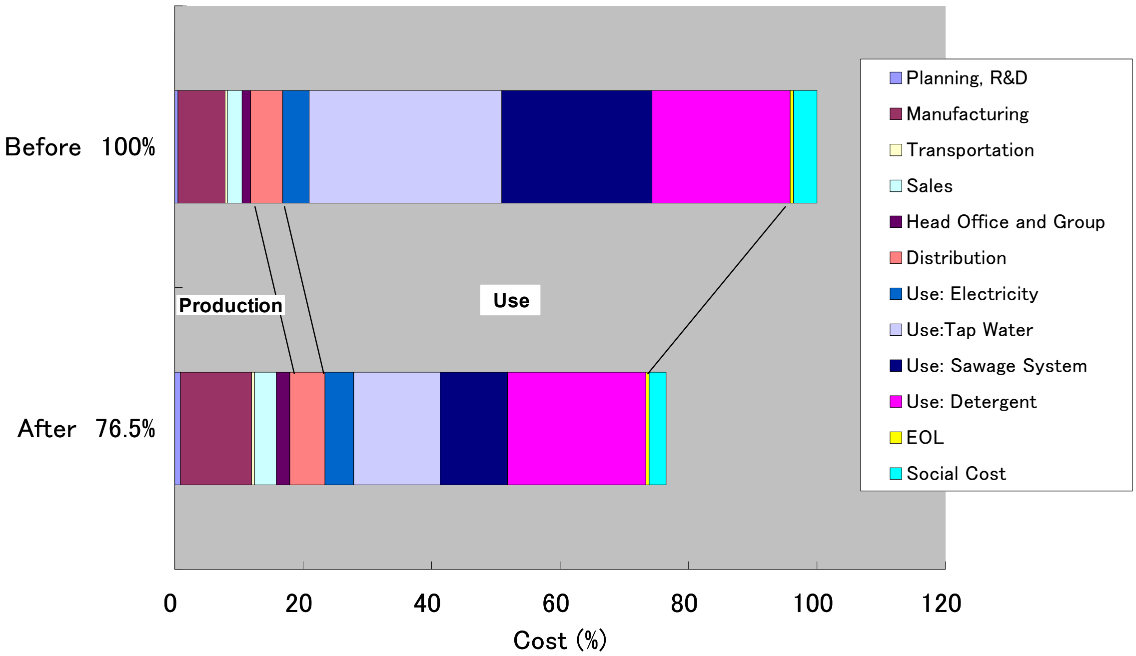

Figure 8. Full-cost accounting for washing machines before and after dewatering and water recirculation (Yamaguchi et al., 2006, 2007a and 2007b).

2.4. Social life cycle assessment

Discussions on how to deal with social and socio-economic criteria of products throughout a product life cycle started in the 1980s. One of the first initiatives were the German *Projektgruppe oekologische Wirtschaft* (Project Group on Ecological Economics within Öko-Institut)[10] in 1987 and the SETAC workshop report on a conceptual framework for LCIA in 1993 (Fava et al., 1993). Both initiatives already aimed to combine social aspects with an environmental assessment of products, and were therefore early contributions towards a holistic assessment.

Recognizing the need for the integration of social criteria into LCA, in 2009 the UNEP/SETAC Life Cycle Initiative published the *Guidelines for Social Life Cycle Assessment of Products* (UNEP/SETAC, 2009a). These aspects assessed in S-LCA are those that may (in)directly affect stakeholders. This publication was motivated by a consensus that 'the use of LCA is hampered in developing countries clearly due to lack of expertise, data, etc., but also due to the inability of LCA to engage in developing countries' key issues (UNEP/SETAC, 2009a, p. 18). Key experts in the field of social responsibility, sustainability and life cycle assessment engaged actively in the development of the publication.

The guidelines provide a map for stakeholders and offer a foundation to allow a larger group of stakeholders to assess the social and socio-economic impacts of products' life cycles.

While it is recognized that the S-LCA is complementary to the other life cycle assessment techniques, there are areas where further research and development are needed, such as:

- the relationship between the function and the product utility;
- methodological sheets for the stakeholder subcategories to support the inventory analysis needs;
- methods for the assessment of impacts and cause-and-effect relationships for social and socio-economic aspects;
- areas of protection;
- scoring systems;
- review process guidance;
- communication formats; and
- the relationship between LCC and S-LCA, etc.

Interest in using S-LCA is growing. This is highlighted in the several case studies that are now available from the 'consumer electronics' (i.e. notebook computer, e-waste) and 'agro-industrial products' (i.e. roses, wine) sectors. From the results of the more comprehensive studies, it can be retained that a product with a good environmental performance is not necessarily produced along the life cycle in a socially responsible way (see the example of Franze, Ciroth 2011b on the S-LCA of roses).

2.4.1 What is social life cycle assessment and how is it applied?

A social life cycle assessment (S-LCA) is described as 'a social impact (and potential impact) assessment technique that aims to assess the social and socio-economic aspects of products and their potential positive and negative impacts along their life cycle' (UNEP/SETAC, 2009a). These aspects assessed in S-LCA are those that may (in)directly affect stakeholders. The impacts may be linked to the behaviours of enterprises, to socio-economic processes, or to impacts on social capital.

The UNEP/SETAC guidelines propose that S-LCA conforms to the ISO 14040 framework – however, with some adaptations (Grießhammer et al., 2006). Again, an S-LCA is carried out in four

10 This is also the basis of Öko-Institut's ongoing work in Product Sustainability assessment (PROSA): see Appendix A.

phases: (i) goal and scope of the study; (ii) inventory; (iii) impact assessment; and (iv) interpretation.

Phase 1 Goal and scope

Phase 1 consists of the definition of goal and scope. This phase also includes a description of the functional unit, a more detailed description of the product utility, a first overview of the stakeholders concerned and the setting-up of boundaries. In principle, all life cycle stages should be considered, unless the person commissioned to carry out the assessment can give good reason why one or more life cycle stages are not relevant from a social or socio-economic impact viewpoint.

Phase 2 Inventory

Phase 2 is concerned with the development of the inventory: here, a first identification of sub-categories is carried out. This selection should be completed in consultation with the stakeholders concerned before proceeding with the inventory itself, as it is during consultation that different or additional topics of concern may be raised. At each geographic location in the value chain, social and socio-economic impacts may be observed by five main stakeholder categories: (i) workers/ employees; (ii) local community; (iii) society (at national and global levels); (iv) consumers; and (v) value chain actors.

Each cluster of stakeholders has shared interests because of its similar relationship to the investigated product systems. Other categories of stakeholders (e.g. non-governmental organizations [NGOs], public authorities/state and future generations) or further differentiations or subgroups (e.g. management, shareholders, suppliers, enterprise partners) can also be added.

The stakeholder categories provide a comprehensive basis for the articulation of the subcategories. UNEP/SETAC (2010) has identified 31 subcategories which are classified according to stakeholders as well as impacts (see Fig. 9).

For example, the subcategory 'child labour' relates to the stakeholder category 'workers' (see Fig. 10 for other examples). Indicators are also developed for the subcategories concerned (i.e. 'worker age' is an inventory indicator in the case of the subcategory 'child labour'). They can be either qualitative (i.e. risk level of corruption practices in the sector) or quantitative (i.e. number of working hours) and cannot always be summed up along the different unit processes. Due to the characteristics of the indicators required, data are not only collected at the level of the unit processes (i.e. an energy power station) or facilities (i.e. any individual production site), but also

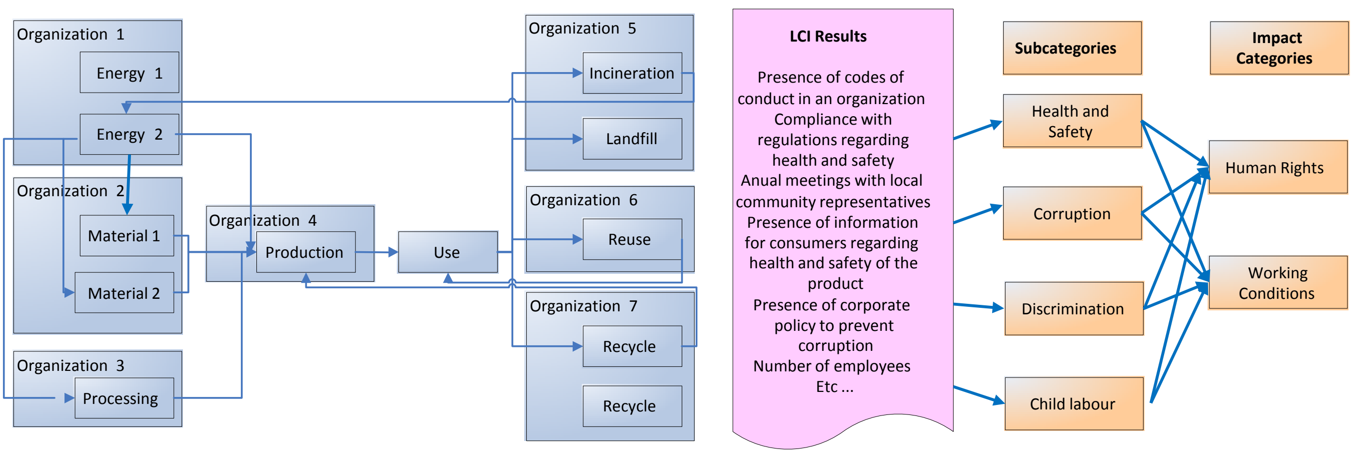

Figure 9. Examples of a social life cycle inventory (S-LCI) and interrelationships to subcategories and impact categories.

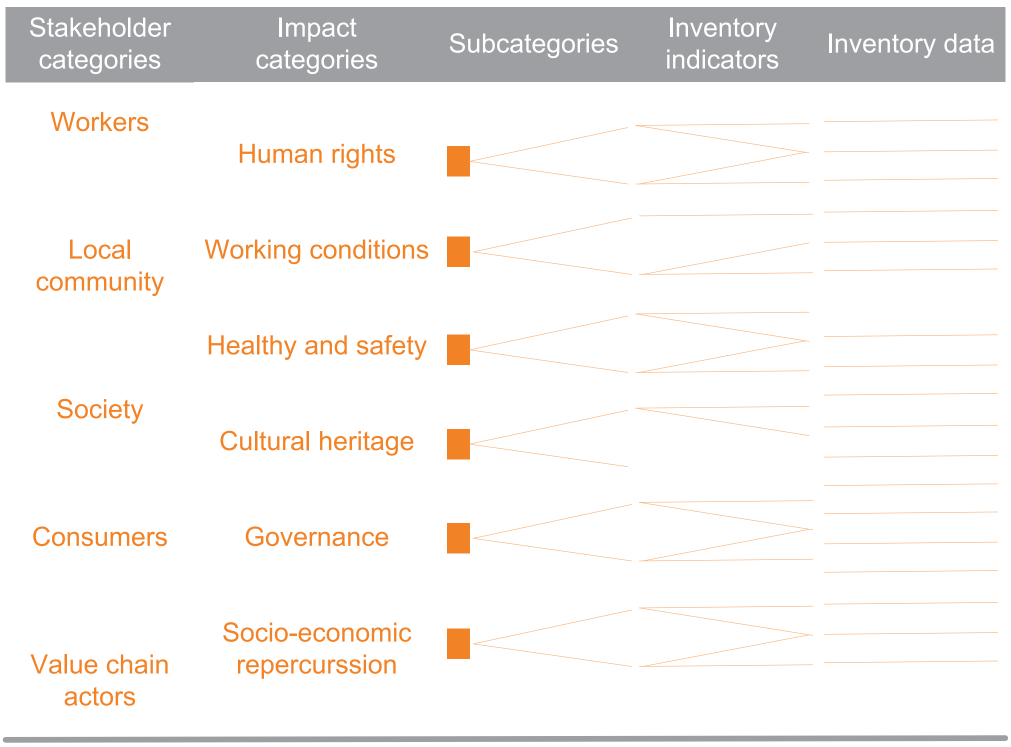

Figure 10. Assessment system from categories to unit of measurement (adapted from Benoît et al., 2007).

at the organizational (i.e. all production sites and administrative offices of an active enterprise), national and global levels. Data at the national or global levels are called 'generic data'. Examples of life cycle inventory results and their interlinkages with the stakeholder groups and categories are provided in Figs 9 and 10, respectively.

Phase 3 Impact assessment

Regarding the impact assessment phase, the UNEP/SETAC *Guidelines for Social Life Cycle Assessment of Products* neither proposes impact assessment methods and models nor interpretation approaches.

Phase 4 Interpret results

Users of studies that are based on inventory results (e.g. 1000 units of a product creates 10 jobs, but 1 out of 10 workers is 15 years old) should develop their own judgement based on national requirements and ethical concerns carefully. This step corresponds to some extent to Phase 4 in an (environmental) LCA.

A review is recommended according to ISO 14040 and a consultation with stakeholders. However, S-LCA is still at an early stage of application, so there are very few examples at this point of this process (Valdivia et al., 2010).

CASE STUDY

S-LCA of cobalt ore (heterogenite) in Katanga, Democratic Republic of Congo

Growth of the cobalt (heterogenite) market is driven by the boom in demand for battery applications in electric vehicles and electronic devices, such as digital cameras, mobile phones, notebooks and cars. In 2010, the Democratic Republic of the Congo (DRC) supplied 51% of the global cobalt production, mainly through artisanal mining. About 100,000 miners and their families are either partially or fully dependent on this activity for their livelihood. The artisanal extraction of cobalt in DRC occurs in a post-war context of widespread poverty, corruption and ethnic tensions, combined with cross-border trafficking and the decline of state-owned industries. This case study investigates a broad range of social issues that hold significant relevance for many products used day to day.

Phase 1 Goal and scope of the study

The study assessed the social impacts of the production of heterogenite and provided a basis for identifying intervention strategies for improving the social standards of artisanal cobalt mining. The system boundaries of the S-LCA included *digging or extraction by manual means, washing, crushing, sorting and packing of heterogenite*. The functional unit was 'the production of one 50 kg bag of ore, grading 3 to 20% cobalt'.

Phase 2 Social life cycle inventory

Data on social impacts of the production of heterogenite were collected for the subcategories defined in the UNEP/SETAC Guidelines on S-LCA. The stakeholder categories considered were: workers, local communities and society. The stakeholder categories related to consumers and value chain actors were excluded from the scope of the study because they were not represented during the extraction of cobalt ore (heterogenite) (Fig. 11).

Data-collection activities took place between November 2010 and June 2011. Data was collected both on site (in the Katanga area of DRC) and using an intensive literature review – including reports from universities, international organizations, research institutes and NGOs, as well as a review of legal texts, official statistics, company reports and local media. The literature research was complemented by telephone interviews with selected experts on mining in DRC.

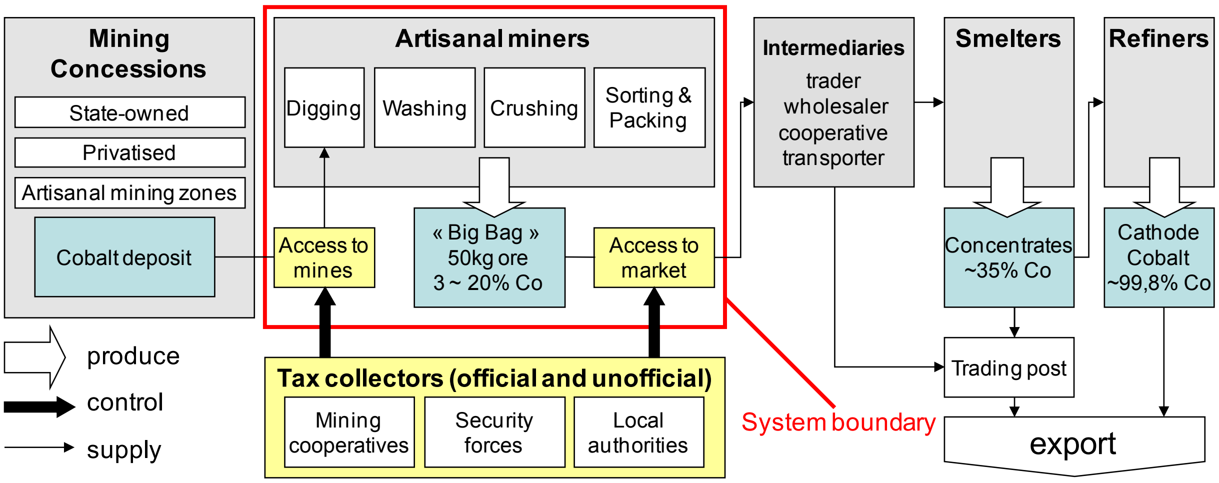

Figure 11. System boundaries of the study of a social life cycle assessment (S-LCA) for cobalt production in Katanga, Democratic Republic of Congo (DRC).

Table 5. Selected examples of social impacts on workers and local communities as a result of artisanal mining of cobalt in Katanga, Democratic Republic Congo.

Stakeholder Category: Workers	
Subcategory	Impact description
Child labour	28% of the total workers are children under the age of 15 (legal limit in DRC), some of them are as young as 6.
Fair salary	A miner usually earns between US$3 and US$5 for a day's work, although sometimes a concentrate deposit can yield up to US$30 a day. (Average daily expense in Katanga for a five-person household is US$2.5.) The revenue is comparatively higher for digging (a task forbidden to women) than for carrying bags and is lowest for washing, crushing, sorting and packing of ores (US$1 to US$3 per day). In the artisanal mining sector in Congo there is little employment security or saving possibilities. Artisanal miners tend to remain in poverty although they earn more than in other sectors of the informal economy.
Working hours	Compared to working hours in the formal private sector (39 hours/week), a full-time artisanal miner performs between 52 and 59 hours/week (additional 35% to 52% workload) and thus exceeds the threshold of 48 hours/week for mine work and even the maximum workload of 56 hours/week including overtime work, as defined by the International Labour Organization (ILO) Convention on Working Hours[10] in Industries. Working hours are de facto limited by daylight in legal or tolerated artisanal mines. Due to low incomes, miners, however, undertake activities at night in guarded mine pits, while undergoing the risk of assault by security personnel.
Health and safety	Significantly higher urinary concentrations of As, Cd, Co, Cu, Pb and U were observed among communities living in a radius of 10 km from mines or smelting plants, especially children, compared to control subjects living in a 400km-radius. For instance, urinary concentration of Co was 7 times, Pb 2 times, Cd 3 times and U 7 times higher in the communities living in a radius of 10km from mines or smelting plants than those of a control group. Uranium associated with cobalt exposes some diggers to radiation levels of 24 mSv/year. As a comparison, the recommended dose limits is 1 mSv/year for the general public, 20 mSv/year for normal radiation workers (ICRP 2007) and 250 mSv/year for liquidators at the Fukushima nuclear disaster (Japanese Government, 2011).
Indigenous rights	It is acknowledged that indigenous communities in the DRC have the right to manage lands that they have traditionally inhabited, cultivated or exploited in any way according to customary principles (DRC, 1973: Land Law, Art. 387–389). Therefore, the Code of Conduct of Artisanal Miners (Annex V) stipulates that miners should follow the local customary laws and traditions (DRC, 2003). However, it is common practice for mining companies to try to negotiate an agreement that serves the interests of the traditional owners (chiefs) rather than the broader needs of the community. Furthermore, given that people employed in the mining sector – compared to the local agricultural based communities – have higher incomes, their presence generates local inflation and access to essential goods can become difficult for indigenous communities. As a consequence, local residents often choose to become involved in mining as well, or provide services to miners, abandoning livelihoods that might be more sustainable in the long term. Eventually, interactions with mining communities is often reported to lead to negative social impacts within the indigenous group, such as increase of polygamy and prostitution, excessive consumption of drugs and alcohol and deterioration of familial and social cohesion (PACT, 2007).

10 C1 Hours of Work (Industry) Convention, 1919: Convention Limiting the Hours of Work in Industrial Undertakings to Eight in the Day and Forty-eight in the Week, Website: http://www.ilo.org/ilolex/english/convdisp1.htm

Phase 3 Social life cycle impact assessment

An impact assessment was conducted on the sub-category level for each stakeholder group and not at the level of (midpoint) impact categories. Table 5 gives an example of the results for selected subcategories of social impacts for workers and local communities. For other subcategories, please refer to Tsurukawa et al., 2011.

In terms of social impacts on stakeholder category 'society', several subcategories, such as contribution to national economy and national budget, employment creation, unjustifiable risks, impact on conflicts etc. were also described in Tsurukawa et al. (2011).

Phase 4 Interpretation/policy advice and intervention

The study summarizes measures to foster a shift from artisanal mining to semi-mechanized small-scale mining cooperatives, in particular by enforcement of the Assistance and Supervision Service for Artisanal and Small-scale Mining. Provision in the Mining Code should also be made to allow private enterprises to lease plots in their concessions that are suitable for such cooperatives. Nevertheless, an integrated approach including infrastructure development (roads, electricity, water, etc.) is essential to enhance competitiveness of other sectors and attract the workforce to alternative livelihoods in order to ensure economic diversification.

CASE STUDY

LCA of an ecolabelled notebook computer – consideration of environmental and social impacts along the entire life cycle

Phase 1 Goal and scope

The case study describes the analysis using an S-LCA combined with an (environmental) LCA of the social and environmental impacts of the life cycle of a notebook computer with EU 'ecolabel' certification. The goals of the investigation were to apply the UNEP/SETAC guidelines for conducting an S-LCA on a complex case, in order to identify social and environmental hot spots (see Glossary) in the life cycle of the computer and to derive recommendations at the enterprise as well as at the policy level in order to improve the sustainable performance of the notebook.

As a functional unit, a specific notebook computer for office use, as it is available in the Belgian market, was selected. The relevant market segment was lightweight notebooks with a long battery life.

The investigated life cycle ranged from: *raw material extraction processes*; *the production of the basic and intermediate products*; *the notebook computer design and final assembly*; *use*; *reuse*; *and recycling*.

The system boundary of the S-LCA differs from that of the (environmental) LCA (see Fig. 12). For simplification reasons

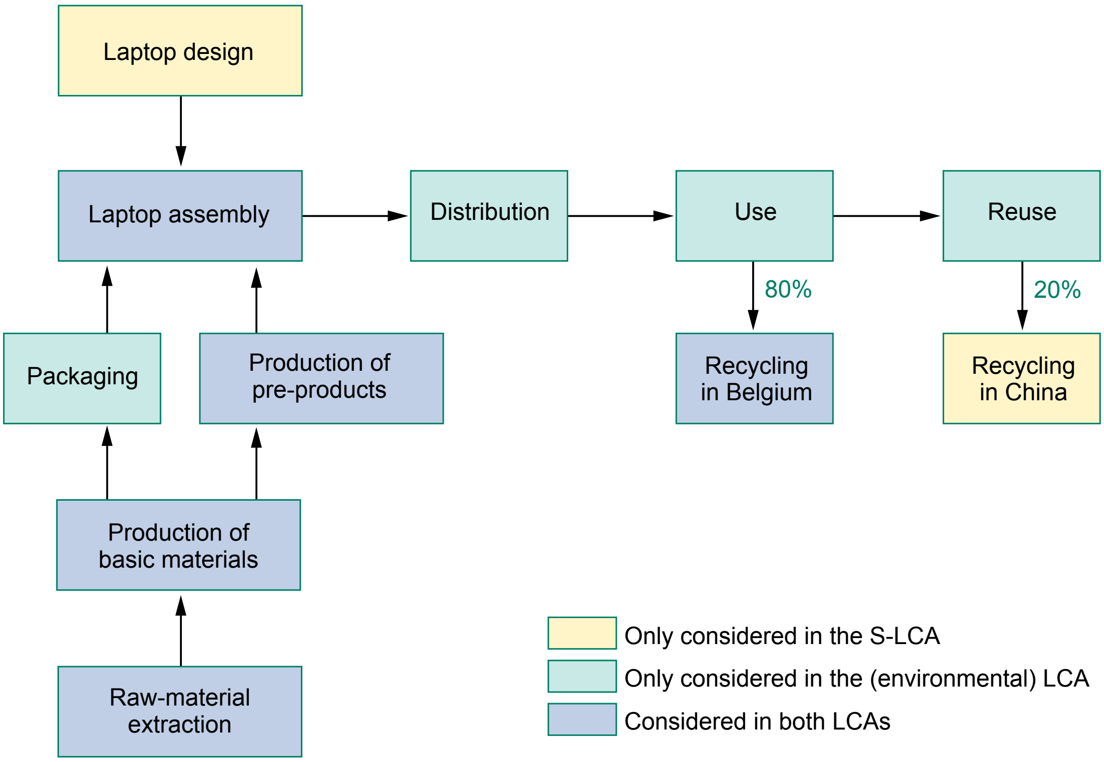

Figure 12. System boundaries considered in the notebook computer study (Ciroth and Franze, 2011a).

the S-LCA did not cover packaging, transport and energy production processes, including upstream chains. In addition, following a first screening of social impacts based on stakeholder feedback and expert judgement, the use phase was not considered since most of the social impacts were identified in the production and the end-of-life phase. However, the use phases were covered indirectly by the consumer stakeholder group, which was considered in the assembly process.

The system boundary of the (environmental) LCA was broader. In addition to main processes, it also included transport, energy production and packaging. The design process was not considered and the informal recycling process could not be analysed because of lack of data.

Phase 2 Inventory

The starting point for both inventories was the disassembly of the notebook. This revealed suppliers, production locations and beyond that, weight and other characteristics of the modules contained in the computer. Inventory parameters for the S-LCA were based on the UNEP/SETAC approach: five main stakeholder groups (workers, local communities, society, value chain actors and consumers), and 30 themes of interest (subcategories) (child labour, forced labour, access to material resources, corruption, etc.). 88 indicators (e.g. ages of workers, number of working hours, number of jobs created, etc.) to measure the status of the subcategories were determined.

The main data sources were reports from enterprises, government organizations and NGOs. During the study, questionnaires were sent to the manufacturer and firsttier suppliers. In several cases also, interviews with workers/employees were conducted. This meant that field data ('raw data' according to the Global Guidance Principles [UNEP/SETAC, 2011]), were collected for those processes that were considered to be the most important. The (environmental) LCA was based mainly on commercial databases currently available. Several processes were adapted to the specific case: for instance, electricity and transport processes were modified based on regional conditions; materials and weights of components were modified based on product-specific data.

Phase 3 Impact assessment

In order to address the social impacts of the notebook, an impact assessment method was developed and applied in the study. The method assessed each subcategory with a colour scale from green (good performance/positive impact) to red (poor performance/negative effect) twice (Fig. 13):

1. The first assessment phase evaluated the performance of the specific enterprise/sector compared to performance reference points based on international standards and conventions. These reference points, coordinated with stakeholders during the project, defined desirable and undesirable indicator values and therefore defined the benchmark applied in the impact and performance assessment.
2. The second assessment phase considered the impacts which result from the enterprise/sector performance on the six impact categories related to working conditions, health and safety, human rights, indigenous rights (including cultural heritage), socio-economic repercussions and governance. The impact categories are also based on the UNEP/SETAC guidelines (UNEP/SETAC, 2009a).

To allow aggregation and to take data gaps into account a factor was assigned to every colour and the averages were calculated on stakeholder and process level.

The environmental impacts were calculated with ReCiPe in the hierarchist version.[12] Both a midpoint and an endpoint assessment were carried out. To identify relevant impact categories, a normalization step was also conducted.

Phase 4 Interpretation

First, the study demonstrated that the consideration of social and environmental aspects in parallel and for a complex product life cycle is possible. Second, the investigation showed that it is necessary to consider both social and environmental impacts to better understand the sustainable performance of a product. Both LCAs provide reasonable results, despite different perspectives and despite methodological challenges due to the novelty of the S-LCA approach and data gaps.

Social hot spots were found in every stage of the product life cycle. In particular, informal activities in the mining and the recycling sector were found to cause serious social problems – not only for workers but also for local communities and the society. Beyond that, the production phase of the notebook computer was linked to poor enterprise performance and negative impacts, while the design phase and the formal recycling were in general uncritical.

From a stakeholder perspective, workers were most affected in investigated subcategories, but also local communities and the society were negatively affected within the life cycle of the notebook

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12 For more information see: http://www.lcia-recipe.net/

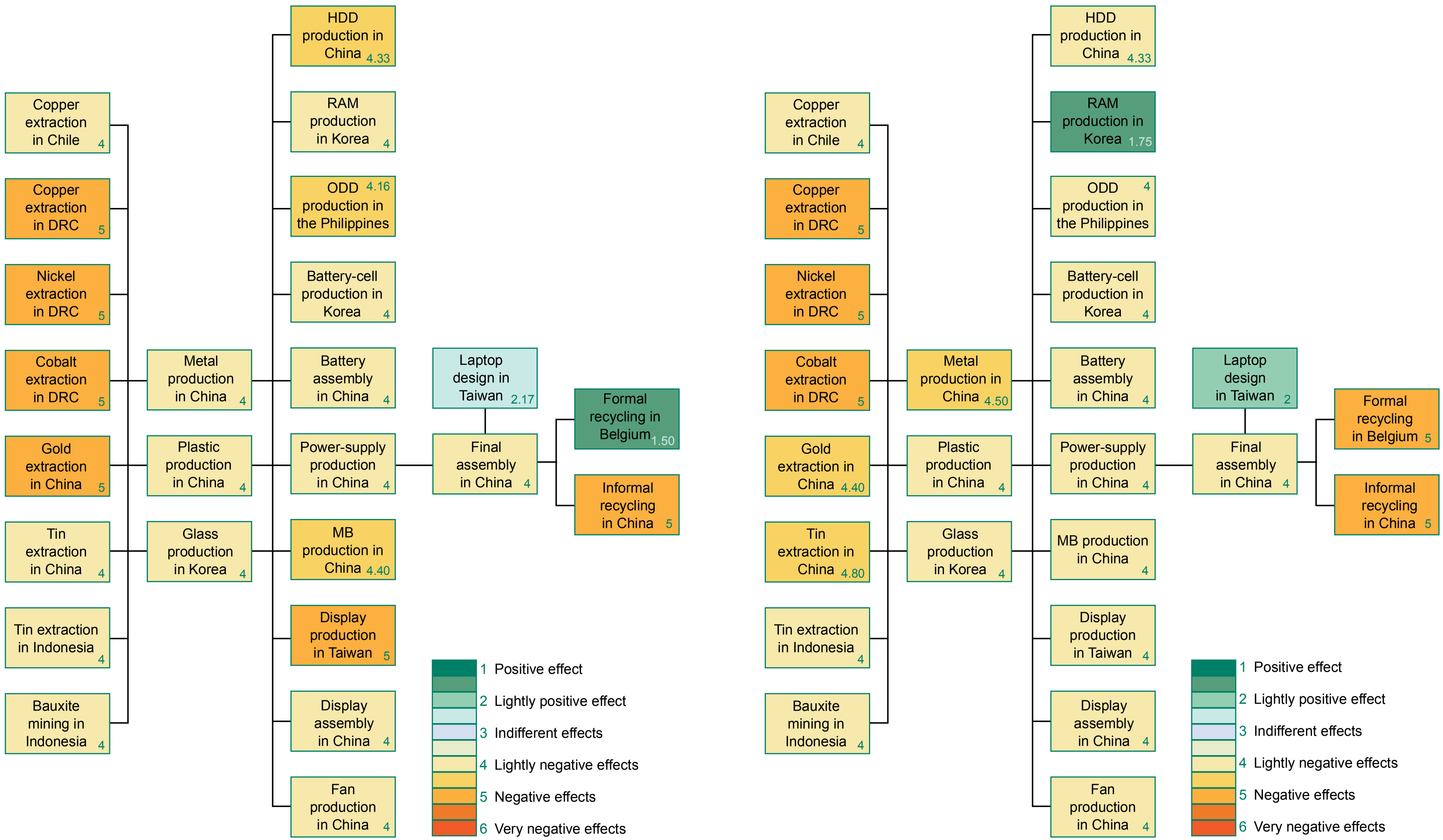


Figure 13 (a). Summary of the S-LCIA for stakeholder group local community (left) and society (right) (Ciroth and Franze, 2011a).

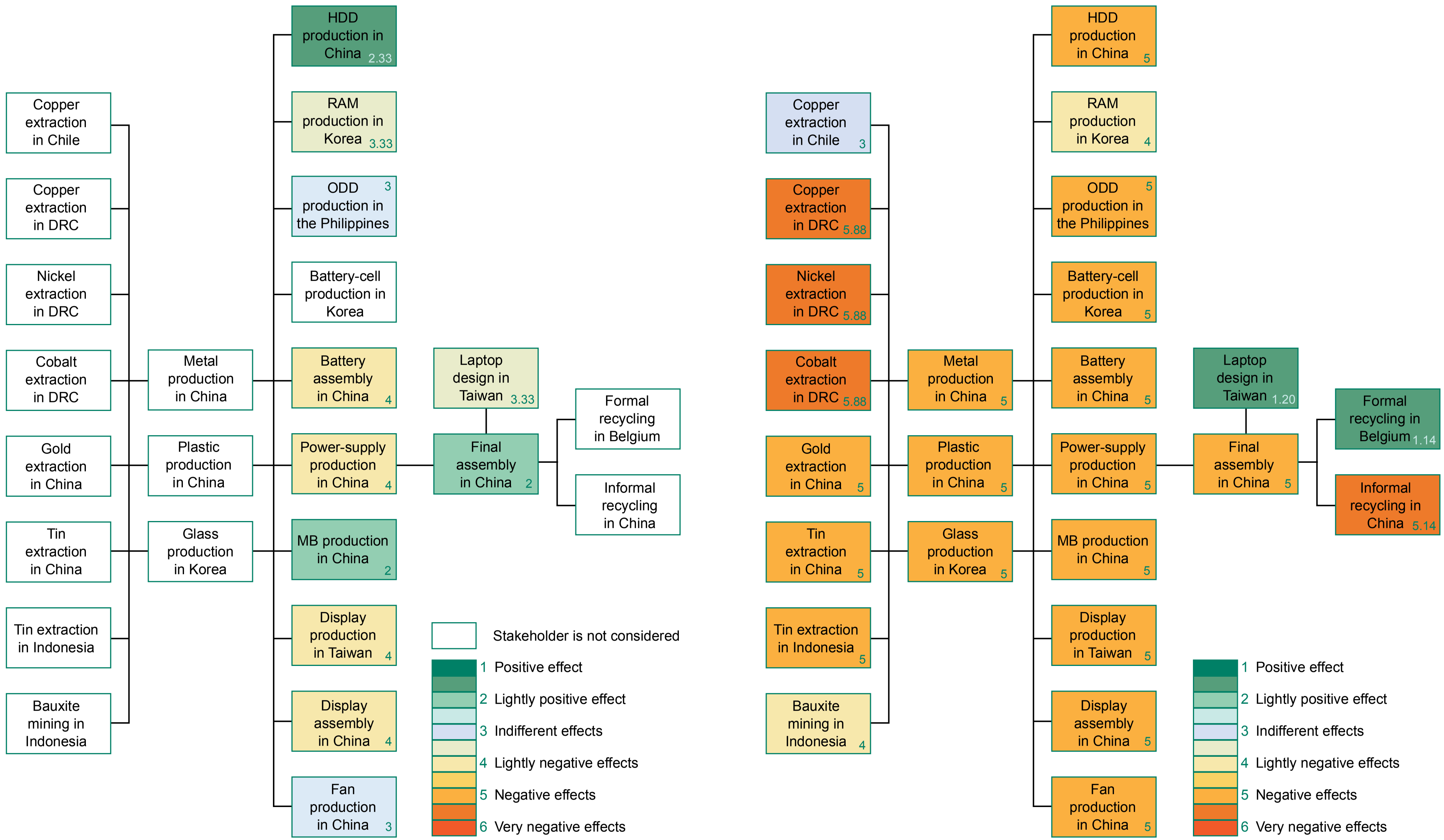


Figure 13 (b). Summary of the S-LCIA for stakeholder group value chain actors (left) and worker (right) (Ciroth and Franze, 2011a).

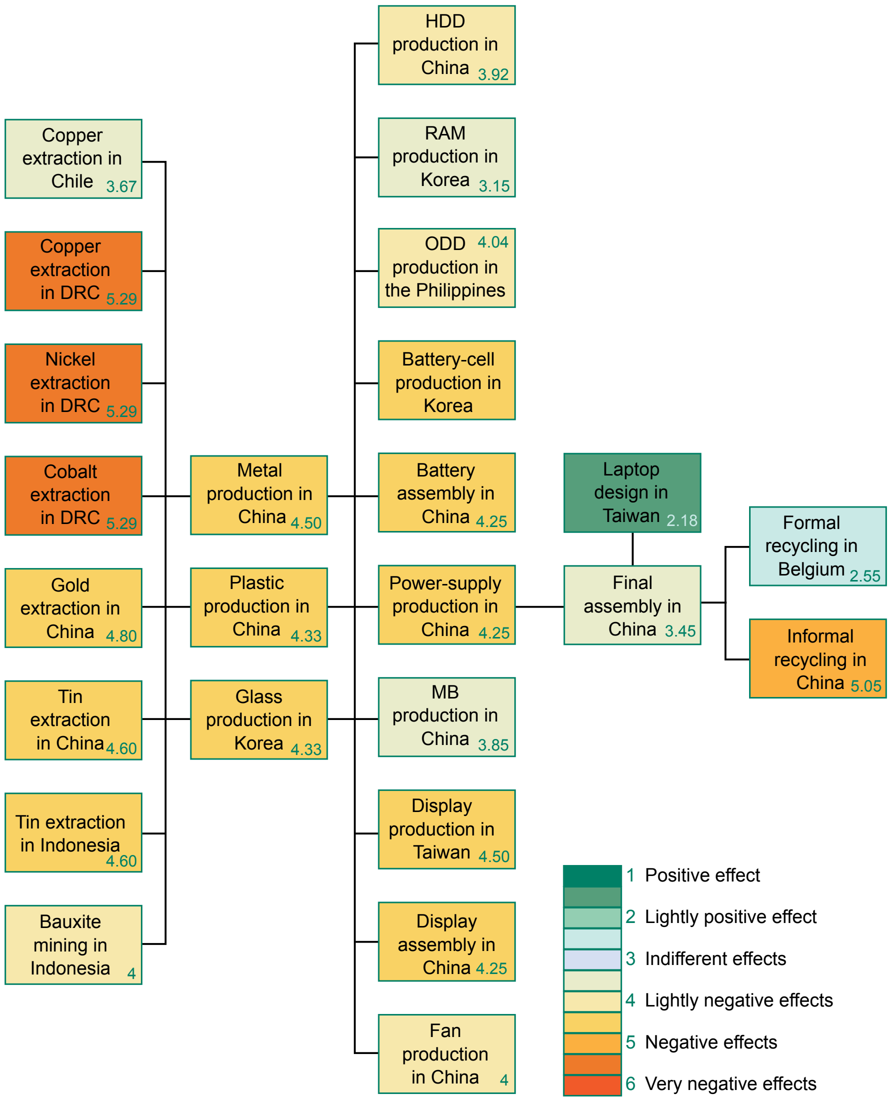


Figure 13 (c). Summary of the S-LCIA for all considered stakeholder groups (Ciroth and Franze, 2011a).

computer. Negative effects occurred especially in least developed countries and emerging economies, but issues regarding social effects were also relevant in advanced economies. The value chain actors were not affected by social hot spots, although here also problems could be detected, such as anti-competitive behaviour or lack of transparency.

The assessment revealed a correlation between the development status of a country and social hot spots. For instance, similarities were found in the mining sector and in the electronic industry in emerging economies.

The environmental profile of the notebook computer was strongly dominated by the production phase. In addition, transport and use added a noticeable contribution to the environmental burden, with different relevance in midpoint and endpoint assessment. Packaging and disposal have a rather low contribution in the midpoint perspective and hardly any in the endpoint assessment.

A comparison of the S-LCA and the (environmental) LCA shows that social and environmental hot spots are partly congruent – for mining operations or the production phase, for instance. However, there are differences: negative environmental effects do not automatically entail social hot spots and this is also true the other way round. In addition, social and (environmental) LCAs look at different issues. Social impacts are only to some extent related to environmental impacts: freedom of expression or discrimination are not linked to the environment, for example. Likewise, there can be environmental effects without direct social repercussions.

3 Life Cycle Sustainability Assessment in Practice

This section gives general indications and recommendations on how to start a life cycle sustainability assessment (LCSA) by showing how the approaches described in this publication ([environmental] LCA, S-LCA and LCC) can be combined to carry out an LCSA.

To illustrate how an LCSA can be carried out, this section includes two case studies: one giving a step-by-step illustration of starting an LCSA on Italian marbles slabs (see Section 3.1, Traverso et al., 2009) and a second on how to apply the three life cycle based techniques towards an LCSA approach in a Chinese e-waste management application (see Section 3.2, Lu et al., 2009).

3.1 Conducting a step-by-step life cycle sustainability assessment

As noted previously, ISO 14040 specifies the life cycle assessment framework for (environmental) LCA in four phases, which can be applied to LCC and S-LCA: (i) goal and scope definition, (ii) inventory analysis, (iii) impact assessment, and (iv) interpretation.

This framework allows for iterative procedures among phases. As the assessment unfolds, data limitations and new insights or stakeholder views can lead to a redefinition of the study focus, goals or methods.

Phase 1 LCSA goal and scope

The first phase of an LCSA – goal and scope definition – describes the purpose, delimitation and the target audience of the study.[13] (Environmental) LCA, LCC and S-LCA have different aims and this must be understood clearly when working towards a combined approach. While taking into account these differences, *a common goal and scope* are strongly recommended when undertaking a combined LCSA.

The goal in the LCSA of the Italian marble slabs case study is to assess the performance of the product from the extraction of raw materials to the manufactured and finished product. The assessment is based on the application of the three techniques: S-LCA, (environmental) LCA and LCC. The marbles analysed are the so-called 'Perlato di Sicilia' and 'Bianco Carrara', the most exported Italian marble types. The target audience for this study consists of the involved enterprises for internal assessment and other similar enterprises to improve their sustainability performances. Moreover, the results can support local governments in the producing areas. Please note that this example does not consider all aspects covered in Chapter 3.

13 More aspects of the scope definition could be defined according to ISO 14040/14044 and the UNEP/SETAC *Guidelines for Social LIfe Cycle Assessment of Products* (UNEP/SETAC, 2009).

3.1.1 Functional unit

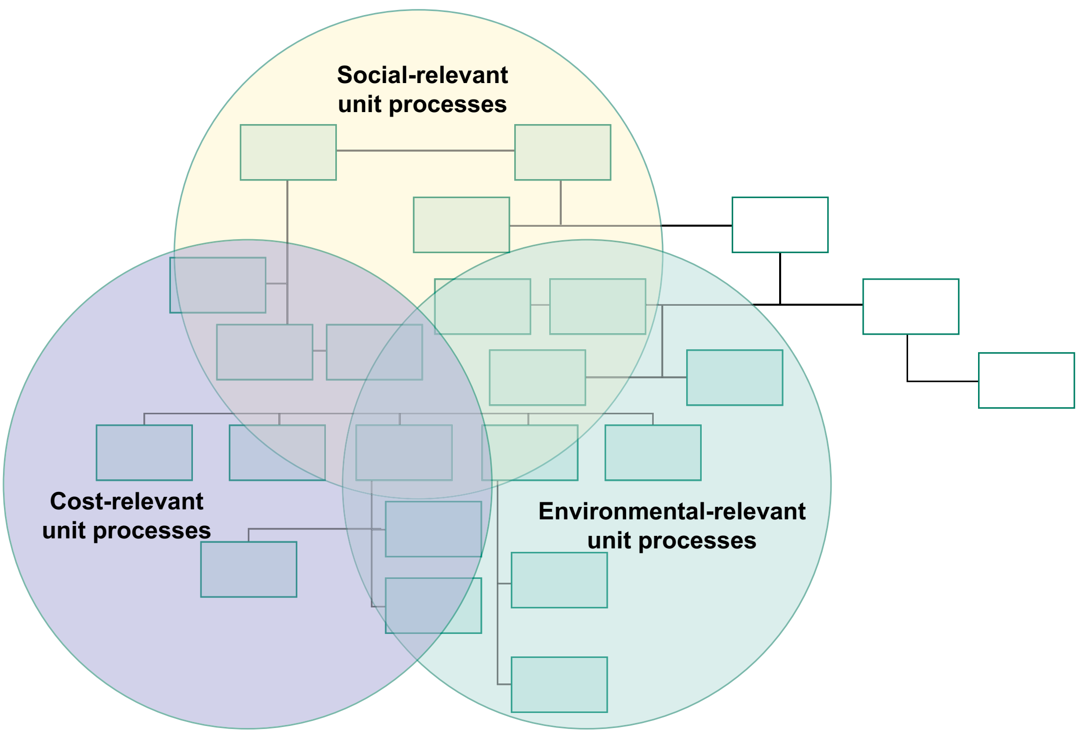
In an LCSA, the inventory and impact indicators must be related to a common product functional unit, which is the basis of all techniques described. As with the S-LCA (UNEP/SETAC, 2009a), it is recommended that the functional unit describes both the technical utility of the product and the product's social utility.

The functional unit of the Italian marble slabs study is the production of 1 m^3 of marble. Four types of marble were studied: Marble A (Perlato di Sicilia 1), Marble B (Perlato di Sicilia 2), Marble C (Bianco Carrara) and Marble D (Bianco Carrara). Marbles function to cover and insulate buildings and surfaces. By having better isolated spaces, the quality of interior environments is improved. It also improves the aesthetics and is easier to maintain.

3.1.2 System boundary

When applied individually, each life cycle technique tends to draw different system boundaries based on their relevancy to aspects of sustainability. In practical terms, in order to identify the relevant unit processes of each technique a cut-off criterion is used (based on mass, energy, working hours, cost, prices, environmental or social relevance, for example). Figure 14 below gives an example of unit processes that are relevant for each of the techniques and in some cases relevant for more than one. For example, in LCC, the system boundary typically broadens to include the R&D department. However, because this activity might be less relevant in terms of environmental and social impacts, it is generally not included in (environmental) LCA and S-LCA (UNEP-SETAC, 2009a).

Therefore, it is recommended that the overall LCSA system boundary contains all unit processes relevant for at least one of the techniques (see Fig. 14 which shows all unit processes included within the circles). In cases where one or more life cycle stages are not assessed in an LCSA study, the reason for the exclusion should be justified.



Unit processes not included in the system boundary

Figure 14. System boundaries of a life cycle sustainability assessment (LCSA).

The system boundary of the Italian marble slabs study included only three main process units: (i) quarry, (ii) manufacturing sawmill and (iii) finishing sawmill. When looked at in detail, the system consisted of extraction and cutting in the quarry, cutting and resin finishing in the first sawmill, polishing and buffing in the second sawmill, the transportation of products along the routes from quarry to two sawmills and the transportation of spoils and scraps to specific landfills. With regard to marble and for the purposes of this example, the impacts during the use stage were considered as negligible. The disposal phase of these products was ignored in this analysis because it was temporally and physically separated from the production cycle. Because of their material durability, marble products frequently last as long as the buildings in which they are used.

The system boundary in the marble slabs case was identical for the three approaches applied. Quantitative cut-off rules were not applied.

3.1.3 Impact categories

For an LCSA study, it is recommended that all impact categories that are relevant across the life cycle of a product are selected. These should follow the perspectives provided by each of the three techniques and consider the stakeholder views[14] when defining the impact categories.

Furthermore, by considering all relevant impact categories from a cross-media, multi-dimensional (social, economic and environmental), inter-generational and geographic perspective, potential trade-offs can be identified and assessed.

14 More about stakeholder engagement is presented in Section 3.2.

The global warming potential is one example of an impact category considered in the (environmental) LCA of 1 m^3 of marble. This was calculated using the characterization factors of the midpoint categories according to the CML approach as described in Guinée et al. (2002) with updated characterization factors.[15]

Regarding LCC impact categories, according to Swarr et al. (2011b), 'aggregated cost data provide a direct measure of impact and thus, there is no comparable impact assessment step in LCC'. Therefore, examples of impact categories for marble are raw materials costs and waste-disposal costs.

For S-LCA, the potentially most affected stakeholder groups identified are the workers and local community groups. (An example of a subcategory considered is 'fair salary'.) According to the methodological sheets for subcategories of the S-LCA guidelines (UNEP/SETAC, 2010), 'this subcategory aims to assess whether practices concerning wages are in compliance with established standards and if the wage provided is meeting legal requirements, whether it is above, meeting or below industry average and whether it can be considered as a living wage'.

3.1.4 Allocation in LCSA in cases of multiple output processes

This discussion is only relevant when quantitative data is used and if a process results in more than one output; then, the question is to which of them the burdens should be allocated. In order to do so, the use of physical or economic proportions is suggested, as it is accepted practice when implementing the three techniques separately.[16]

15 This can be obtained from the website http://cml.leiden.edu/software/data-cmlia.html.
16 Please refer to ISO 14040/14044 for more detailed guidelines about allocation procedures.

In the LCSA Italian marble slabs-production study, no need for allocation was identified.

Phase 2 LCSA inventory

In LCSA, the LCI compiles exchanges between unit processes and organizations of the product system and the external environment which lead to environmental, economic and social impacts. Because of the importance of achieving *consistency with the three techniques, it is recommended that data is collected at the unit process and organizational level* (see Fig. 15).

The availability of data is another aspect that must be considered; this may be a critical issue in developing countries and in small and medium enterprises when conducting an LCSA. One important issue to consider is the type of data that needs to be collected. S-LCA data is characterized not only by quantitative, but also by qualitative and semi-quantitative information. *Therefore, it is recommended that while applying an LCSA, all three types of data are collected along the life cycle.*

While (environmental) LCA and LCC data can be found in enterprises and organizations, public statistics and databases, there is still a lack of social LCA data. However, some databases for generic data are under development. Moreover, considering that site-specific and generic data (i.e. average national or regional data) are used in the three techniques, it is recommended that while implementing an LCSA, *both types of data* are taken into account. Some examples of the type of data collected when starting an LCSA is presented in Table 6.

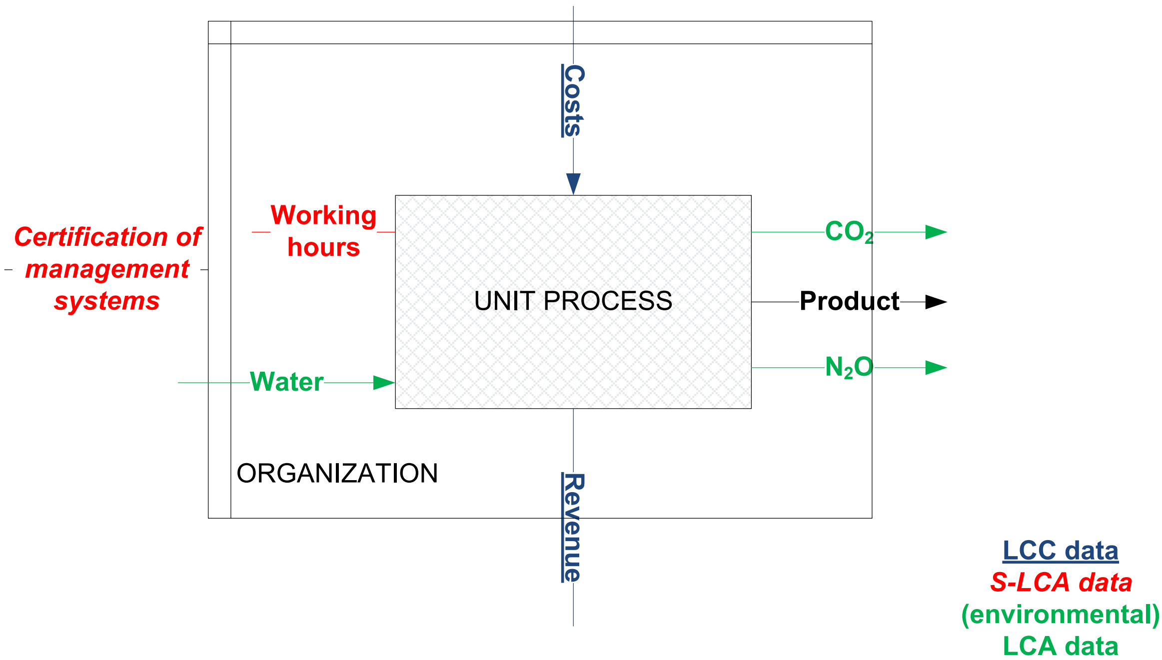


Figure 15. Example of life cycle sustainability assessment (LCSA) inventory data for unit process and organization levels.

Table 6. Example of life cycle sustainability assessment data for marble slabs case study (Traverso and Finkbeiner, 2009).

(Environmental) LCA data	LCC data	S-LCA data
Energy consumption	Fuel costs	Total employees
Natural resources	Water-disposal costs	Wages
Water use	Electricity costs	Accidents
CO_2	Labour costs	Child labour
NO_x	Revenues	Working hours
SO_2	Raw material costs	Employees - Employees gender

Phase 3 Impact assessment

It is recommended that the classification and characterization steps are implemented as the minimum and mandatory steps according to ISO 14040 (2006) and ISO 14044 (2006) in order to proceed with the impact assessment in LCSA. Again, please note that LCC does not have a comparable impact assessment step, since aggregated cost data provide a direct measure of impact.

In the classification step, inventory data are assigned to the impact categories selected and this is feasible in LCSA. However, considering that characterization models are not available for all impact categories and impacted environments, it may neither be possible to convert all LCSA inventory data into common units nor to aggregate them within each impact category required by the characterization step. *It is recommended, whenever feasible, that a combined framework for impact assessment based on the individual S-LCA, LCC and (environmental) LCA frameworks (example in Fig. 16) is used.*

Although normalization, aggregation and weighting are optional steps according to ISO 14040, *any aggregation and weighting of results of the three techniques used are not recommended* because of the early stage of LCSA research and implementation and because the individual aims of each of the techniques applied are not directly comparable to the other.

Phase 4 LCSA interpretation

The overall objective of an LCSA is to provide a combined assessment of a product system. The results of an LCSA will show not only the negative impacts but also the benefits.

It is recommended that the results are read in *a combined fashion based on the goal and scope definition.* The evaluation results may help to clarify: if there are trade-offs between economic benefits and environmental or social burdens; which life cycle stages and impact subcategories are critical; and if the product is socially and environmentally friendly by understanding the impacts of the products and materials on society.

When evaluating the results, it is recommended that data quality is taken into account. This refers to the characteristics of data and its ability to satisfy stated requirements (UNEP/SETAC, 2011). Interpreting the results in a combined fashion can be difficult and presenting clear LCSA

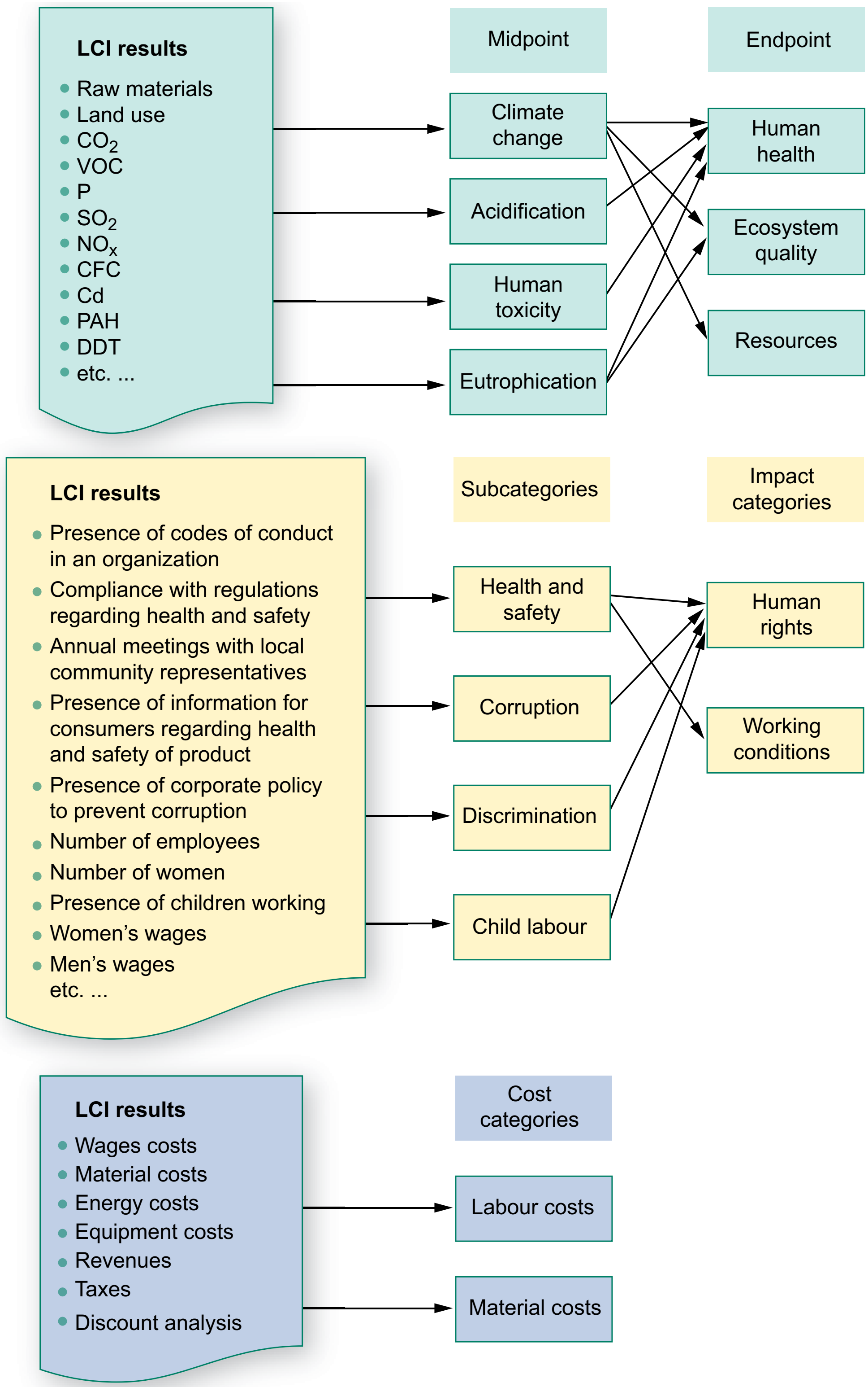


Figure 16. Examples of midpoint and endpoint categories, subcategories of stakeholders and cost categories when starting a life cycle sustainability assessment (LCSA).

results to compare similar products to support decision-making processes is a key challenge (Traverso and Finkbeiner, 2009; Hardi and Semple, 2000; Jesinghaus, 2000; Weidema, 2006).

Traverso et al. (2009) try to address this challenge by introducing the 'Life Cycle Sustainability Dashboard' (LCSD). This is an adaptation of the Jesinghaus's dashboard of sustainability (2000), which was originally developed to assess several communities by integrating economic, social and environmental factors.

The life cycle sustainability dashboard consists of a macro written in MS EXCEL®, which allows for comparison of two or more products based on scores and colours. In this approach, the indicators are grouped into a limited number of topics. It is therefore possible to set up a 'bespoke' dashboard choosing the appropriate topics and associated indicators. In order to implement the Life Cycle Sustainability Dashboard, the indicator sets used for [environmental] LCA, LCC and S-LCA can be used and inserted in the LCSD database. All the inventory data for each considered product can be added within each technique (S-LCA, LCC and [environmental] LCA). The adapted tool ranks the totals obtained for each technique and presents the results in dark green for best performance and dark red for worst.

Figure 17 presents the results obtained for four different marble slabs (A, B, C and D) and the three techniques applied (S-LCA, LCC and [environmental] LCA) in different colours according to their performance (Capitano et al., 2010). The data for each are represented in Table 7. The results suggest that Marble C (Bianco Carrara) has the best performance assessed under the three techniques. Furthermore, it is clear that there are trade-offs in the cases of Marbles A, B and D, because while Marble B has better S-LCA results than Marble A, it presents worse

Table 7. Example of LCSA impact assessment results for a marble slabs case study (Traverso and Finkbeiner, 2009).

Products	(environmental) LCA						LCC					S-LCA								
	E01	E02	E04	E05	E06	E07	L01	L03	L04	L05	L06	S01	S02	S03	S04	S06	S07	S08	S09	S10
	Embodied energy	Global warming potential	Human toxicity potential	Photochemical ozone creation potential	Acidification potential	Eutrophication potential	Extraction and production costs	Fuel costs (diesel and methane)	Waste disposal costs	Electricity costs	Revenues	Total number of employees	Female employees	Employees with unlimited contract	Employees with limited contract	Child labour	Working hours	Wage for working hour	Workers with health insurance	Workers with yearly check-up
	MJ	kgCO2 eq	kg p-DCB eq	kg ethylene eq	kg SO2 eq	kg PO4--- eq	€/m3	€/m3	€/m3	€/m3	€/m3	n/m3	n/m3	n/m3	n/m3	n/m3	n/m3	€/h	n/m3	n/m3
Perlato di Sicilia A	1,224.16	186.51	0.93	0.03	0.75	0.07	251.02	16.58	0.51	39.17	422.59	0.0053	0.000154	0.00071	0.0000615	0	8.243077	0.000633	0.000769231	0.000769
Perlato di Sicilia B	1,470.52	257.49	1.01	0.0373	0.9774	0.0626	213.75	27.61	0.05	28.8	0	0.00278	0.000652	0.0019569	0	0	1.548237	0.000184	0.001956947	0.001957
Bianco Carrara C	698.66	109.9	0.37	0.015	0.425	0.037	89	n.d.	1	2	550	0.00796	0.00317		0.0002228	0				
Bianco Carrara D	1414.77	37.4	0.96	0.025	0.789	0.098	20	n.d.	n.a	0.96	550	0	0		0	0				

Note: p-DCB = para-dichlorobenzene or 1,4-dichlorobenzene (environmental) LCA and LCC results than Marble A. Moreover, Marble D has the best economic performance of the four but not good social and environmental performances.

3.2 Additional LCSA issues

Additional general or overarching issues – such as the time-horizon, the level of stakeholder engagement and whether a review process should be carried out – may also need to be taken into account. Ways to handle them are presented below.

Inventory results (Table 7)

Products	(environmental) LCA						LCC				
	E01	E02	E04	E05	E06	E07	L01	L03	L04	L05	L06
	Embodied Energy	Global Warming Potential	Human Toxicity Potential	Photochemical oxidation potential	Acidification potential	Eutrophication potential	Extraction and production costs	Fuel costs (diesel and methane)	Waste disposal costs	Electricity costs	Revenues
	MJ	kgCO2 eq	kg p-DCB eq	kg ethylene eq	kg SO2 eq	kg PO4--- eq	€/m3	€/m3	€/m3	€/m3	€/m3
Perlato di Sicilia A	1,224.16	186.51	0.93	0.03	0.75	0.07	251.02	16.58	0.51	39.17	422.59
Perlato di Sicilia B	1,470.52	257.49	1.01	0.0373	0.9774	0.0626	213.75	27.61	0.05	28.8	0
Bianco Carrara C	698.66	109.9	0.37	0.015	0.425	0.037	89	n.d.	1	2	550
Bianco Carrara D	1414.77	37.4	0.96	0.025	0.789	0.098	20	n.d.	n.a	0.96	550

Products	SLCA								
	S01	S02	S03	S04	S06	S07	S08	S09	S10
	Total number of employees	Female employees	Employees with unlimited contract	Employees with limited contract	Child labour	Working hours	Wage for working hour	Workers with health insurance	Workers with yearly check up
	n/m3	n/m3	n/m3	n/m3	n/m3	n/m3	€/h	n/m3	n/m3
Perlato di Sicilia A	0.0053	0.000154	0.00071	0.0000615	0	8.243077	0.000633	0.000769231	0.000769
Perlato di Sicilia B	0.00278	0.000652	0.0019569	0	0	1.548237	0.000184	0.001956947	0.001957
Bianco Carrara C	0.00796	0.00317		0.0002228	0				
Bianco Carrara D	0	0		0	0				

Presentation of results

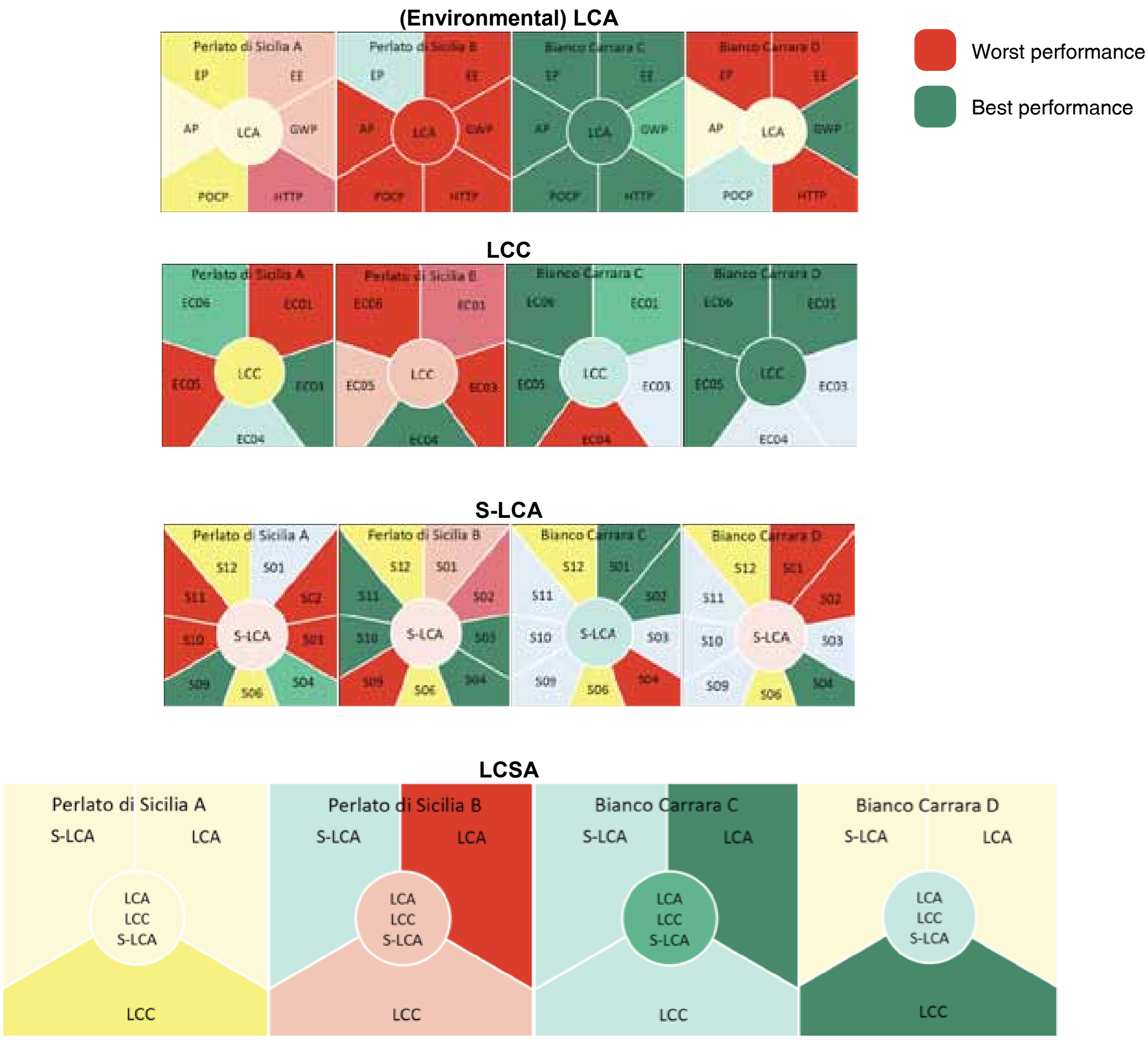


Figure 17. Presentation of LCSA results of the marble slabs study (Capitano et al., 2011).

3.2.1 Horizon aspects of an LCSA study

A time-horizon has different perspectives in (environmental) LCA, LCC and S-LCA, so it is recommended to take this into consideration.

3.2.2 Stakeholder engagement

It is very important to involve and engage stakeholders at each relevant geographic location, whenever possible. The following stakeholder groups should be consulted: workers/employees, local community, society (including organizations advocating the interest of future generations), consumers and value chain actors.

3.2.3 Review

As noted above, ISO 14040 (2006) and ISO 14044 (2006) mandate peer review when (environmental) LCA is used for public assertions and comparisons. It is also recommended that a peer review is carried out for LCC and S-LCA. Therefore, *it is recommended that a review is carried out for comparative purposes.*

Independent qualified reviewers should be familiar with the requirements of (environmental) LCA and LCC and have the appropriate technical expertise. For the analysis of social indicators, the consideration of third parties' (stakeholder) opinions and feedback on the indicators elaborated is important.

In addition, it is recommended that *the stakeholder views are considered when drawing the conclusions of the peer review.*

CASE STUDY
LCSA application in waste management

LCSA has an enormous potential to be applied in the waste management field – for example, in relation to wastes from electrical and electronic equipment (WEEE).

WEEE are the most rapidly increasing solid waste in the world; reuse, which is normally considered the preferable end-of-life option, is not always feasible in the local context of many countries because of technological, economic, institutional and market-based constraints.

In China the situation is no different and, therefore, the overall goal of the LCSA presented below was to examine the sustainability aspects of different end-of-life strategies of WEEE and provide policy-makers and other stakeholders with solutions (Lu, 2009). The specific aims were to:

- distinguish the waste-recycling strategies with the lowest environmental impacts;
- help decision-makers choosing cost- and eco-efficient waste recycling modes; and
- identify positive and negative social impacts of the waste-recycling activities and scrutinize options for improvement and negative impacts avoided in real practice.

The functional unit chosen for this case study carried out in 2009 was the treatment of one desktop PC (without screen). The referred system included the collection, disassembly, shredding, sorting, materials recovery, components, re-manufacture and waste disposal unit processes. Two different systems options are compared: (A) informal and (B) formal waste collection and treatment systems (see Table 8).

Table 8. Life cycle costing (LCC) results of two WEEE recycling options in China (Lu, 2009).

Cost & benefits (Chinese yuan [CNY])	Option A	Option B
Payment to sellers of WEEE	6.00	6.00
Transportation cost in city	0.05	0.00
Long distance transportation cost	1.40	1.40
Pre-treatment cost	0.20	1.00
Material recovery cost	0.60	0.50
Price paid by the consumers	16.93	19.50
Added value	8.68	10.60

To carry out the (environmental) LCA, the Eco-indicator 99 method[17] was chosen. 'Cost-benefit analysis' was the tool used for the LCC. The stakeholder category analysed within the S-LCA related to workers and local community groups, with human health, wages and job creation subcategories.

Figure 18 shows that the results of the (environmental) LCA indicate that Options A and B are similar in terms of the collection and transportation stages, but that this is not the case for the treatment and disposal stages where Option (B) has lower impacts.

17 Eco-indicator 99 is a damage-oriented method for LCA (http://www.pre.nl/content/eco-indicator-99).

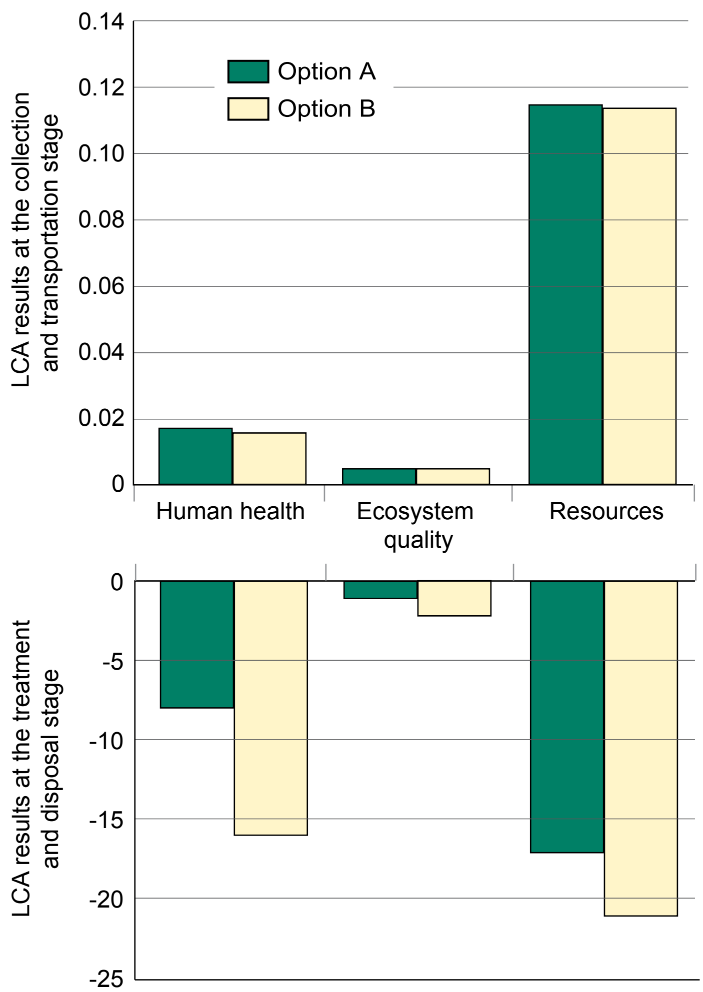


Figure 18. (Environmental) LCA results of WEEE recycling options in China (Lu, 2009).

The LCC results showed that Option B offers more economic benefits than Option A. While in Option B, there is less employment creation, wages are higher than in Option A. However, health conditions are better in Option B.

Table 9. S-LCA results of general WEEE recycling options in the informal sector China (Lu, 2009) (in Chinese yuan [CNY]).

Stakeholder category	Subcategory	Impact description
Workers	Fair salary	Low (30-50 CNY/day)
	Working hours	Long (8–11 hours/day)
Society	Number of jobs created	700,000 (98% in the informal sector)

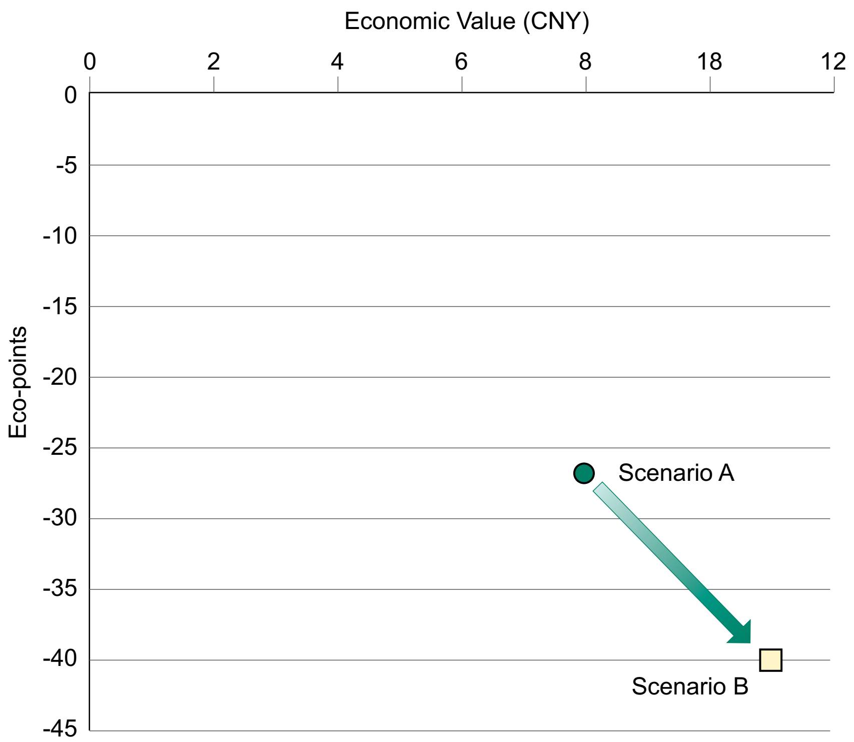
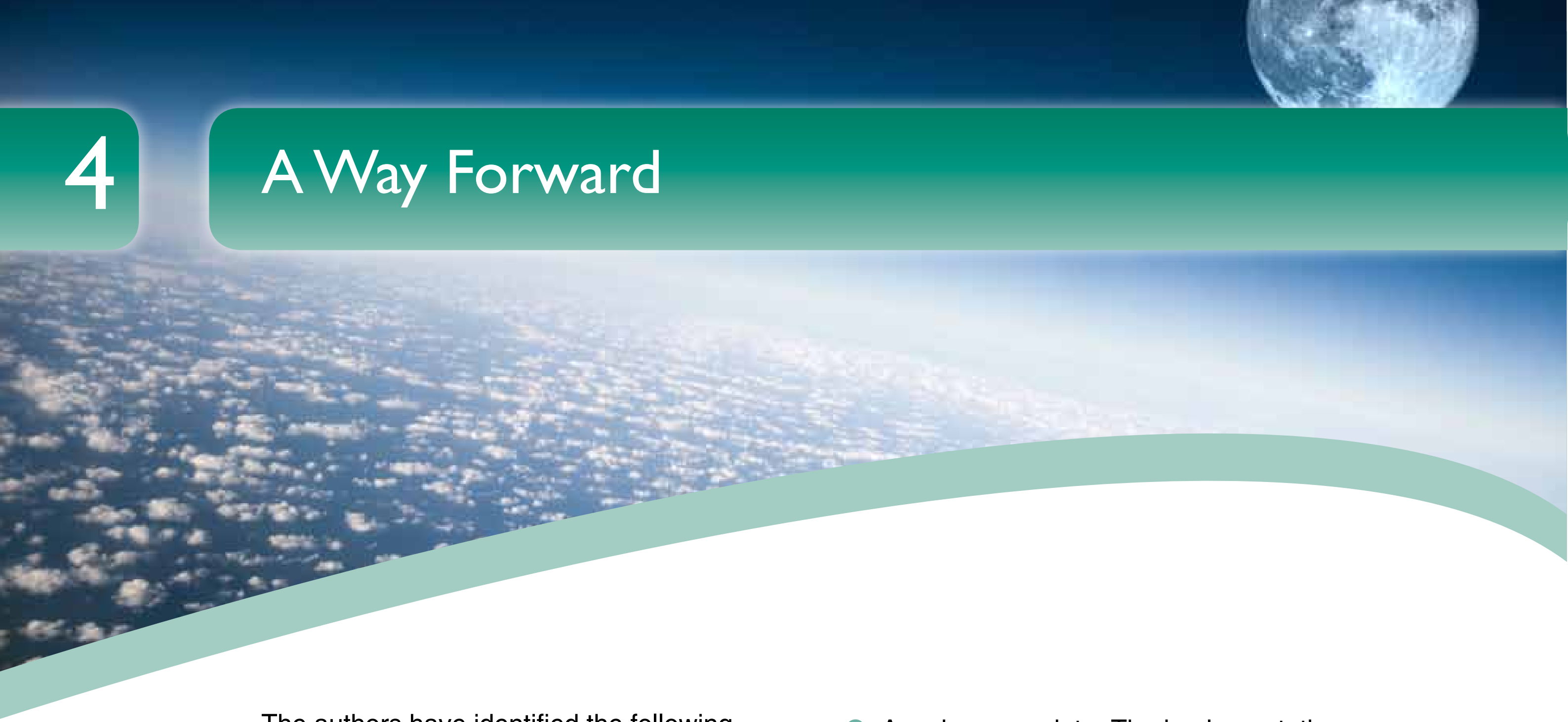


Figure 19. Presentation of combined LCC and (environmental) LCA results of a WEEE recycling options in China (Lu, 2009).

The conclusions are as follows:

- Recycling involving formal collection and waste treatment (Option B) offers higher economic benefits and wages and lower environmental impacts (see Fig. 19) due to the better quality and higher prices of materials recovered and the cleaner production practices.
- Option A offers more opportunities for job creation (see Table 9) but more severe health impacts (see Fig. 18). Hence, if the local region is interested in promoting it, an improved Option A version should be strived for.

- Governmental departments responsible for waste management can also design more appropriate waste-management policies based on LCSA results.
- LCSA can be used by waste-recycling practitioners to choose sustainable end-of-life strategies with lower impacts for the supply chain workers, for example.
- Results from the individual techniques applied indicate that Option B offers higher economic benefits due to the better quality of materials recovered and indicates less environmental impacts since cleaner production practices are implemented.



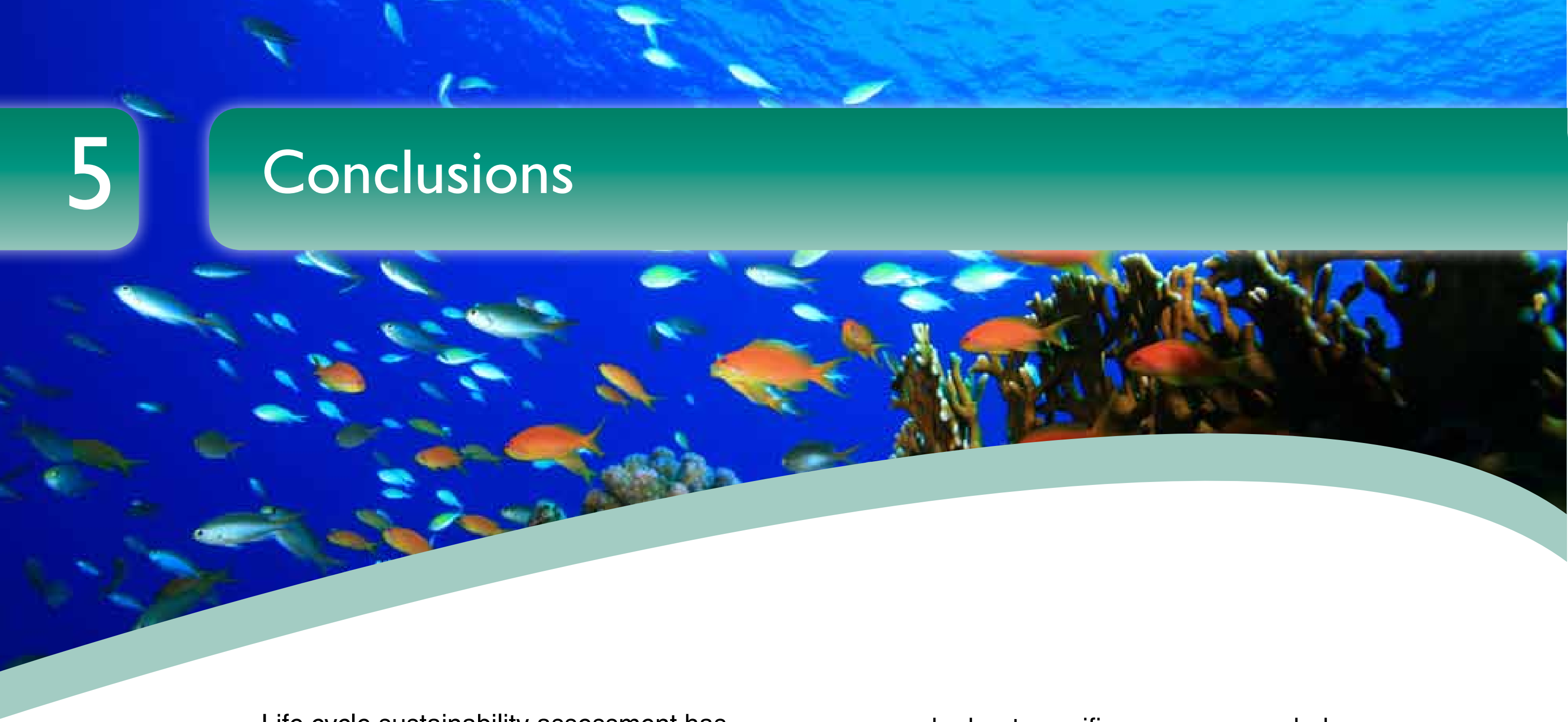
4 A Way Forward

The authors have identified the following areas that need more development in order to advance the implementation of LCSA tools:

- Strengthen more applications by combining (environmental) LCA, LCC and S-LCA and obtain findings and lessons learned. For example, with more LCSAs, 'trade-off errors' in sustainability decision support should be overcome – for example, not supporting a product chain that is environmentally positive but socially questionable, not claiming that a product is more sustainable because it uses less resources, or has lower direct carbon emissions, without assessing other aspects needed in a sustainability assessment.
- Develop technical expertise. This is essential, and is particularly true for developing countries and emerging economies where there is a lack of financial resources and local capabilities. This means that international and intergovernmental organizations must support national efforts hand-in-hand with essential local partners, such as national life cycle networks, centres of excellence, national cleaner production centres, chambers of commerce and industrial associations.
- Acquire more data. The implementation of consistent and harmonized data-management systems for each of the techniques (LCC, S-LCA and [environmental] LCA) may support the broader availability of data and promote the generation of data – especially in developing countries and emerging economies. Subsequently, this will facilitate the implementation of the three techniques in a linked and consistent way.
- Discuss LCSA principles and criteria and explore how to read the results of the LCIAs for each technique in the light of 'trade-off' analysis among the three sustainability pillars. This may help stakeholders to advance the implementation of more case studies and assist decision-makers in making better informed decisions.
- Conduct more research on the assessment of product utility and the sustainability of products in order to avoid the unethical use of the tools.
- Engage actively in the definition process. Common understanding and consensus of the areas of protection (endpoints) within an LCSA is a new field for further discussion, which requires an active engagement of stakeholders and decision-makers in the definition process.

- Address the perspective of the future generation in future research when implementing an LCSA approach to prevent trade-offs between generations and to take account of the Brundtland definition of sustainable development.
- Combine all three dimensions more fluently and promote the exchange and possible convergence of separate schools of environmental, cost and social assessments. This will allow a better understanding of the linkages of their impacts and potential escalation effects. Enhanced methodology on assessment is to be followed by the development of guidance for the interpretation of results which becomes more complicated given the many dimensions and categories.
- Developing more streamlined approaches that analyse the whole picture (instead of looking in high detail only at one aspect) is encouraged. Software and database businesses are asked to facilitate user friendlier and low cost techniques to promote more LCSAs.
- In order to build trust in the combined approach, provide more guidance and examples of stakeholder involvement in LCSAs and review processes to underline the importance of strong involvement of concerned parties (stakeholders).

- Discuss and validate a clearer format for the communication and dissemination of LCSA results to decision-makers in order to support better informed choices on sustainable products.
- To develop LCSA methodology, conduct more research on the circumstances and risks of double-counting when applying the three techniques. Moreover, until the LCSA approach matures, it is recommended that LCSAs initially follow steady-state rather than dynamic approaches. Further research is also needed regarding the time aspect, as while (environmental) LCA and S-LCA usually do not account for the effects of time, it is common in LCC to state the discount rate.



5 Conclusions

Life cycle sustainability assessment has significant potential to be used by enterprises, governments, agencies for international cooperation and other organizations in society (such as consumers' associations) in their efforts to produce and consume more sustainable products. This implies reducing environmental degradation and the use of natural resources in a cost-effective manner, while at the same time contributing to social welfare.

From the cases presented, it can be inferred that existing life cycle based techniques which are currently used independently can be used in a combined way to conduct an LCSA. This approach can be applied in all parts of the world and for all products, providing useful findings for decision-makers. While methods for (environmental) LCA, LCC and social LCA have been developed as stand-alone techniques, their combination in one study allows for integrated decision-making on the triple bottom line of sustainable development: people, planet and profit.

The LCSA proposed is not a re-invention of the wheel – similar approaches have been presented in the past under different names – but it is the first time that a UN publication promotes the vision that finally we are getting the methodologies and data together to move towards an LCSA of products. Certainly, more applications, better data access and further research about specific areas are needed, but we are on the journey. More and more, companies, governments and actors work with experts in obtaining the full sustainability picture of the world behind the products we buy, although this does imply a significant contribution in terms of staff time and financial resources. However, these recent pioneering activities will bring about a data infrastructure in the future – in particular also for S-LCA, so that we will be able to apply an LCSA in a much more cost-effective manner. We have seen this happening in the past with (environmental) LCA, which is becoming better known under the name 'footprinting' and which has seen a significant increase in its usage.

If only one or two of the proposed techniques are used for decision-making processes about sustainable products, opportunities for improvements with regard to the disregarded pillar(s) of sustainable development may be lost and the risks of trade-offs with critical consequences may emerge.

To achieve the aim of a Green Economy with sustainable consumption and production patterns, powerful and credible science-based techniques are required to generate knowledge in the area of resource efficiency and then translate a better understanding of the product system into action. LCSA can play a crucial role in this process, not only for enterprises but also in the context of science-policy interfaces and in the empowerment of consumers in their daily purchasing decisions.

In this way, the present publication *Towards a Life Cycle Sustainability Assessment* contributes to the upcoming United Nations Conference on Sustainable Development (Rio+20) in 2012 . Evidently, in this decade more guidance on a number of methodological challenges and especially huge capability development efforts will be needed to operationalize and eventually mainstream LCSA in product development and marketing and, therefore, to achieve a more sustainable future.

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A

Annex A:
LCSA and Related Initiatives

The need to provide a methodological framework and the urgency of addressing increasingly complex systems are acknowledged globally. This has meant the growth in LCSA initiatives and tools, some of which are listed below:

In 2002 Klöpffer proposed the **LCSA approach**.

LIME (Itsubo and Inaba, 2003) is a Japanese conversion tool that can be used to express endpoint environmental impacts in monetary terms.

Weidema's **impact assessment model** is used to describe the interrelationships between the three sustainability pillars (social, environmental and economic) (Weidema, 2006).

The **sustainability assessment model** (Cavanagh et al., 2006) allows the evaluation of the sustainability of projects.

The **product sustainability assessment tool (PROSA)** (Grießhammer et al., 2007) focuses on an analysis of social, environmental and economic aspects and the utility and consumer aspects of product portfolios, products and services. The tool aims to identify system innovations and options for action towards sustainable development.

In 2008 Klöpffer proposed the first formula conceptualizing the way to combine the three life cycle based techniques which conform to ISO 14040 (2006) and ISO 14044 (2006).

The combination of (environmental) LCA with other assessments was also an aim in the research project CALCAS, carried out within the Sixth Framework of the European Commission. The main result of CALCAS consists of the proposal of a framework for Life Cycle Sustainability Analysis (LCSA). It broadens the scope of current LCA in two main directions: from mainly environmental impacts only to covering all three dimensions of sustainability, and from mainly product-related questions to questions related to sector or even economy-wide levels. Moreover, it deepens current LCA to include also other relations than those technological and environmental presently taken into account (e.g. physical relations, economic and behavioral relations). This is considered as a useful input for the purposes of this publication and the LCSA proposed.

Finkbeiner et al. (2010) emphasize that it is important to provide clear and comprehensive results in addition to robust indicators for all three dimensions. Their **life cycle sustainability dashboard** is presented as an example of a communication tool that can be used for both experts and non-expert stakeholders.

The **SETAC WE-LCA** technique (Poulsen and Jensen 2004) addresses workers' exposures and impacts which are considered as a contribution to the S-LCA and (environmental) LCA. Related concerns are being partially covered by the S-LCA (UNEP/SETAC, 2009a).

The **BASF Socio-Eco-Efficiency Analysis SEEBALANCE®** (BASF 2010 and Saling et al. 2002) has the objective of integrating quantified social indicators into the BASF eco-efficiency analysis, which originally addressed mainly environmental concerns.

EFORWOOD (2010), funded by the European Commission (EC) produced a decision support tool, **tool for sustainability impact**

assessment (ToSIA), for the forestry wood chain. This is based on multi-criteria decision analysis and allows the comparison of indicators of the different sustainability pillars and converts them into a cost-benefit analysis.

Valdivia et al. (2010) and Swarr et al. (2011a) discuss the suitability of an integrated decision-making based on the combination of the three techniques that conform to ISO standards. While the first advocates for global use (especially in the emerging economies and developing countries), the second deepens the discussion on the need to advance the assessment of the economic sustainability dimension.

Halog et al. (2011) emphasize that the combination of (environmental) LCA, LCC and S-LCA needs a '**systems perspective**' in order to provide an integrative and holistic approach to sustainability assessment. They also point to a need for a computational methodology and suggest including a stakeholder analysis supported by a multi-criteria decision analysis and dynamic system models. For further reading, please visit the References list.

The WBCSD's Sustainable Consumption and Value Chain system solution aims to identify what support members' need to integrate new business models, solutions and opportunities for value chain integration, with a particular focus on consumption (WBCSD, 2011). More specifically, WBCSD has the objective of building a vision and a pathway for sustainable consumption by 2050 and of helping companies to improve the sustainability of their value chains.

Most recently, activities that are focused on the implementation of ad hoc LCSA tools and approaches are emerging worldwide. These offer interesting learnings and findings that can be taken into account in advancing LCSA praxis. For example, Spoerri et al. (2011) conducted a comparative LCSA of the industrial supply chains of Swiss beet sugar with cane sugar produced in Brazil in order to allow better informed policy decision making; Vinyes et al. (2011) compared the sustainability of used cooking oil and vegetable oil in order to determine and promote better used-oil-collection systems in Mediterranean countries. Both studies showed evidence that environmentally feasible alternatives do not always contribute to improving social and socio-economic conditions. Trade-offs could be identified in both cases, and it was clear that more appropriate recommendations were needed in order to attain more sustainable products.

B

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Annex B:
Glossary

Term	Explanation/Definition
Allocation	Partitioning the input or output flows of a process or a product system between the product system under study and one or more other product systems (ISO 14040, 2006)
Carbon footprint	A total product carbon footprint is a measure of the direct and indirect greenhouse gas (GHG) emissions associated with all activities in the product's life cycle. Products are both goods and services. Such a carbon footprint can be calculated by performing (according to international standards) an LCA that concentrates on GHG emissions that have an effect on climate change (UNEP/SETAC, 2009b)
Impact category	Class representing environmental issues of concern to which life cycle inventory analysis results may be assigned. ISO 14040 (2006); Impact categories are logical groupings of S-LCA results, related to social issues of interest to stakeholders and decision-makers (UNEP/SETAC, 2009a)
Characterization in S-LCA	In S-LCA, the characterization models are the formalized and – not always – 'mathematical' operationalization of the social and socio-economic mechanisms. They may be a basic aggregation step, bringing text or qualitative inventory information together into a single summary, or summing quantitative social and economic inventory data within a category. Characterization models may also be more complex, involving the use of additional information such as performance reference points (UNEP/SETAC, 2009a)
Characterization factor in (environmental) LCA	Factor derived from a characterization model which is applied to convert an assigned life cycle inventory analysis result to the common unit of the category and/or subcategory indicator (ISO 14040, 2006)
Data quality	Characteristics of data that relate to their ability to satisfy stated requirements (UNEP/SETAC, 2011)
Developing economies	Developing and emerging economies include all countries that are not classified as advanced economies. The International Monetary Fund (IMF) provides a classification that is revised each year in its World Economic Outlook
Discount rate	A discount rate is used to calculate direct present values of future costs. It is usually a combination of inflation and of an interest rate and values are in the range of several percent. Applying the discounting makes future costs less valuable; this takes into account an uncertainty about whether future costs will indeed occur and it also takes into account foregone chances of using money flows earlier
Elementary flow	Material or energy entering the system being studied that has been drawn from the environment without previous human transformation, or material or energy leaving the system being studied that is released into the environment without subsequent human transformation (ISO 14040, 2006)
(Category) endpoint	Attribute or aspect of natural environment, human health, or resources, identifying an environmental issue giving cause for concern (ISO 14040, 2006)
Externalities	By-products of activities that affect the well-being of people or damage the environment, where those impacts are not reflected in market prices. The costs (or benefits) associated with externalities do not enter standard cost accounting schemes

Functional unit	Quantified performance of a product system for use as a reference unit in a life cycle assessment study (ISO 14040, 2006)
Goal and scope	The first phase of an LCA; establishing the aim of the intended study, the functional unit, the reference flow, the product system(s) under study and the breadth and depth of the study in relation to this aim (Guinée, J. 2002)
Inventory indicator	Inventory indicators provide the most direct evidence of the condition or result they are measuring. They are specific definitions of the data sought. Inventory indicators have characteristics such as type (e.g. qualitative or quantitative) and unit of measurement (ISO 14040, 2006)
Life cycle actor	Any organization or person that takes decisions that directly influence the life cycle of a specific product or service, such as producers (who decide where and for which price a product or pre-product is available), users (who decide to buy the product and about the way to dispose of the product) and end-of life actors who may decide about the specific waste and disposal pathways (authors' definition)
Life cycle management	Life cycle management (LCM) is a product management system aimed at minimizing the environmental and socio-economic burdens associated with an organization's product or product portfolio during its entire life cycle and value chain. LCM supports the business assimilation of product policies adopted by governments. This is done by making life cycle approaches operational and through the continuous improvement of product systems (UNEP/SETAC, 2007)
Method	Specific procedure within a technique (UNEP/SETAC, 2007)
Methodology	Coherent set of methods (UNEP/SETAC, 2007)
Midpoint	The term 'midpoint' expresses the point that lies somewhere on the impact pathway as an intermediate point between the LCI results and the damage or end of the pathways (Jolliet et al., 2003b)
Normalization	Calculating the magnitude of category indicator results relative to reference information (ISO 14044, 2006)
Organization	Company, corporation, firm, enterprise, authority or institution, or part or combination thereof, whether incorporated or not, public or private, that has its own functions and administration (ISO 14001, 2004)
Product	Any goods or service offered to members of the public either by sales or otherwise (ISO 26000)
Qualitative indicators	Qualitative indicators are nominative: they provide information on a particular issue using words. For instance, text describing the measures taken by an enterprise to manage stress (UNEP/SETAC, 2007)
Quantitative indicator	A quantitative indicator is a description of the issue assessed using numbers: for example number of accidents by unit process (UNEP/SETAC, 2007)
Scope of the study	The scope is defined in the first phase of the study: it describes the study's depth and breadth. It defines the limits placed on the product life cycle (that can be infinite) and on the detail of information to be collected and analysed. It defines where the data will be coming from, how up-to-date the study will be, how information will be handled and where the results will be applicable (UNEP/SETAC, 2007)
Social hotspots [The term 'Bottleneck' can be used as a synonym for negative hotspots]	Social hotspots are unit processes located in a region where a situation occurs that may be considered as a problem, a risk or an opportunity, in function of a social theme of interest. The social theme of interest represents issues that are considered to be threatening social well-being or that may contribute to its further development (UNEP/SETAC, 2009)
Socio-economic	Socio-economic involves a combination of social and economic factors or conditions (UNEP/SETAC, 2009)

Stakeholder	Individual or group that has an interest in any activities or decisions of an organization (ISO/CD 26000–2008) (UNEP/SETAC, 2009)
Stakeholder category	Cluster of stakeholders that are expected to have similar interests due to their similar relationship to the investigated product systems
Subcategories of impact	A representation/constituent of an impact category (adapted from UNEP/SETAC, 2009)
Sustainable consumption and production	The use of services and related products, which respond to basic needs and bring a better quality of life while minimizing the use of natural resources and toxic materials as well as the emissions of waste and pollutants over the life cycle of the service or products so as not to jeopardize the needs of future generations
Technique	Systematic set of procedures to perform a task
Tool	Instrument used to perform a procedure
Uncertainty	Uncertainty refers to the lack of certainty, e.g. in the prediction of a certain outcome, in a measurement, or in an assessment results. It is a general term used to cover any distribution of data caused by either random variation or bias. In LCA, evaluation or measurement of uncertainty is an on-going process and relates to all the elements of data quality as well the aggregation model used and to the general aims of the study as set in the goal and scope (UNEP/SETAC, 2007)
Unit process	Smallest portion of a product system for which data are collected when performing a life cycle assessment (ISO 14040, 2006)
Value chain	The entire sequence of activities or parties that provide or receive value in the form of products or services (ISO 26000)
Water footprint	Water footprint (WF) is a measure of the impacts of the direct and indirect water consumption associated with all activities in the product's life cycle, including consumption. This is especially relevant for water-intensive processes and at locations where water scarcity is a serious problem (UNEP/SETAC, 2009b)
WE-LCA	Working environmental LCA (WE-LCA) is a compilation and evaluation of the inputs, outputs and potential working environmental impacts on humans of a product system throughout its life cycle (Poulsen and Jensen, 2004)
Weighting	Converting and possibly aggregating indicator results across impact categories using numerical factors based on value-choices; data prior to weighting should remain available (ISO 14040, 2006)

About the UNEP/SETAC Life Cycle Initiative

The Global Life Cycle Initiative was established by UNEP and SETAC. Among other things, the Life Cycle Initiative builds upon and provides support to the ongoing work of UNEP on sustainable consumption and production, such as Industry Outreach, Industrial Pollution Management, Sustainable Consumption, Cleaner and Safer Production, Global Reporting Initiative (GRI), Global Compact, UN Consumer Guidelines, Tourism, Advertising, Eco-design and Product Service Systems.

The Initiative's efforts are complemented by SETAC's international infrastructure and its publishing efforts in support of the LCA community.

The Life Cycle Initiative is a response to the call from governments for a life cycle economy in the Malmö Declaration (2000). It contributes to the 10-year framework of programmes to promote sustainable consumption and production patterns, as requested at the World Summit on Sustainable Development (WSSD) in Johannesburg (2002).

The UNEP/SETAC Life Cycle Initiative's mission is to bring science-based Life Cycle approaches into practice worldwide

Our current work is building on the Life Cycle Initiative's continual strength to maintain and enhance life cycle assessment and management methodologies and build capacity globally. As we look to the future, Life Cycle Assessment (LCA) and Life Cycle Management (LCM) knowledge is the Life Cycle Initiative's anchor, but we will advance activities on LCA and LCM to make a difference within the real world.

Therefore, the renewed objectives are the following ones:

- **Objective 1:** Enhance the global consensus and relevance of existing and emerging life cycle approaches methodology;
- **Objective 2:** Facilitate the use of life cycle approaches worldwide by encouraging life cycle thinking in decision-making in business, government and the general public about natural resources, materials and products targeted at consumption clusters;
- **Objective 3:** Expand capability worldwide to apply and to improve life cycle approaches.

For more information, see

lcinitiative.unep.fr

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About SETAC

The Society of Environmental Toxicology and Chemistry (SETAC) is a professional society in the form of a not-for-profit association, established to promote the use of a multi-disciplinary approach to solving problems of the impact of chemicals and technology on the environment. Environmental problems often require a combination of expertise from chemistry, toxicology and a range of other disciplines to develop effective solutions. SETAC provides a neutral meeting ground for scientists working in universities, governments and industry who meet, as private persons not bound to defend positions, but simply to use the best science available.

Among other things, SETAC has taken a leading role in the development of Life Cycle Management (LCM) and Life Cycle Assessment (LCA).

The organization is often quoted as a reference on LCA matters.

For more information, see www.setac.org.

For more information, see

www.setac.org

About the UNEP Division of Technology, Industry and Economics

Set up in 1975, three years after UNEP was created, the Division of Technology, Economics (DTIE) provides solutions to policy-makers and helps change the business environment by offering platforms for dialogue and co-operation, innovative policy options, pilot projects and creative market mechanisms.

DTIE plays a leading role in three of the six UNEP strategic priorities: **climate change, harmful substances and hazardous waste, resource efficiency**.

DTIE is also actively contributing to the **Green Economy Initiative** launched by UNEP in 2008. This aims to shift national and world economies on to a new path, in which jobs and output growth are driven by increased investment in green sectors, and by a switch of consumers' preferences towards environmentally friendly goods and services.

Moreover, DTIE is responsible for **fulfilling UNEP's mandate as an implementing agency for the Montreal Protocol Multilateral Fund** and plays an executing role for a number of UNEP projects financed by the Global Environment Facility.

The Office of the Director, located in Paris, coordinates activities through:

> **The International Environmental Technology Centre** - IETC (Osaka), which implements integrated waste, water and disaster management programmes, focusing in particular on Asia.

> **Sustainable Consumption and Production** (Paris), which promotes sustainable consumption and production patterns as a contribution to human development through global markets.

> **Chemicals** (Geneva), which catalyses global actions to bring about the sound management of chemicals and the improvement of chemical safety worldwide.

> **Energy** (Paris and Nairobi), which fosters energy and transport policies for sustainable development and encourages investment in renewable energy and energy efficiency.

> **OzonAction** (Paris), which supports the phase-out of ozone depleting substances in developing countries and countries with economies in transition to ensure implementation of the Montreal Protocol.

> **Economics and Trade** (Geneva), which helps countries to integrate environmental considerations into economic and trade policies, and works with the finance sector to incorporate sustainable development policies. This branch is also charged with producing green economy reports.

DTIE works with many partners (other UN agencies and programmes, international organizations, governments, non-governmental organizations, business, industry, the media and the public) to raise awareness, improve the transfer of knowledge and information, foster technological cooperation and implement international conventions and agreements.

For more information,
see **www.unep.org/dtie**

Every day, unsustainable patterns of consumption, unsustainable production methods and population growth challenge the resilience of the planet to support human activities. At the same time, inequalities between and within societies remain high – leaving billions with unmet basic human needs and a disproportionate vulnerability to global environmental change. To counteract this trend, UNEP and SETAC have worked together to develop the current work Towards a Life Cycle Sustainability Assessment. This has been achieved through the UNEP/SETAC Life Cycle Initiative.

A key objective of the UNEP/SETAC Life Cycle Initiative is to help extend life cycle assessment (LCA) methods and practices. One major achievement has been the development of methods and techniques that can measure sustainability and allow LCA to support decision-making toward more sustainable product and process systems. In this way, life cycle techniques can be used to carry out life cycle sustainability assessments. This guidance document provides a starting point for learning about the methodologies and techniques suitable for life-cycle-based ways of measuring sustainability.

Environmental life cycle assessment, life cycle costing and social life cycle assessment are techniques with similar aims and methodological frameworks addressing individually the three sustainability pillars. Towards a Life Cycle Sustainability Assessment shows how it is possible to combine them into an integrated assessment and outlines how they can be used to contribute to an overarching life cycle sustainability assessment (LCSA).

This publication is a natural step in UNEP's work, which has in the past decade focused on developing the 10-Year Framework of Programmes for Sustainable Development and which is now also focusing on economic sustainability through the UNEP Green Economy Initiative. This publication will increase the awareness of stakeholders and decision-makers in governments, agencies for international cooperation, business and consumers' associations who are called on to take integrated and holistic decisions on products.

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