UNIVERSITY OF TURKU

WHAT CAN BE MEASURED CAN BE MANAGED?

A transdisciplinary study in sustainability assessment and management

Hanna Pihkola

TURUN YLIOPISTON JULKAISUJA – ANNALES UNIVERSITATIS TURKUENSIS
SARJA – SER. E OSA – TOM. 73 | OECONOMICA | TURKU 2021

UNIVERSITY OF TURKU

WHAT CAN BE MEASURED CAN BE MANAGED?

A transdisciplinary study in sustainability assessment and management

Hanna Pihkola

TURUN YLIOPISTON JULKAISUJA – ANNALES UNIVERSITATIS TURKUENSIS
SARJA - SER. E OSA – TOM. 73 | OECONOMICA | TURKU 2021

University of Turku

Turku School of Economics
Department of Management and Entrepreneurship
Management and organization
Doctoral programme of Turku School of Economics

Supervised by

Professor Tomi J. Kallio
Turku School of Economics

D.Sc.(Tech.) Kirsi Liikamaa
Turku School of Economics

Reviewed by

Professor of Practice Mikko Jalas
Aalto University, School of Arts, Design and Architecture

Professor Lassi Linnanen
Lappeenranta-Lahti University of Technology

Opponent

Professor of Practice Mikko Jalas
Aalto University, School of Arts, Design and Architecture

ISBN 978-951-29-8346-9 (PRINT)
ISBN 978-951-29-8347-6 (PDF)
ISSN 2343-3159 (Print)
ISSN 2343-3167 (Online)
Painosalama, Turku, Finland 2021

UNIVERSITY OF TURKU
Turku School of Economics
Department of Management and Entrepreneurship
Management and organization
HANNA PIHKOLA: What can be measured can be managed?
A transdisciplinary study in sustainability assessment and management.
Doctoral Dissertation, 90 pp. (+ original papers)
Doctoral Programme of Turku School of Economics
January 2021

ABSTRACT

Lack of environmental data and proper measures for sustainability have been acknowledged as persistent challenges for sustainability management research. Management and organization studies have been criticized for ignoring the natural environment and focusing too much on the economic, organizational and social aspects of sustainability. This study contributes to existing literature on sustainability management by increasing understanding about practical challenges and constraints related to measuring sustainability and communicating the results. This is considered important, taking into account the central role that measurements and metrics play within the literature on sustainability management. Thus, the study addresses some of the fundamental challenges related to sustainability management. According to principles of transdisciplinary research, it uses methods that have been developed in the fields of engineering and industrial ecology, and builds on case studies that originate from the practice-oriented field of sustainability assessment. The specific focus of this study is on the use of product-based life cycle-based assessment methods and life cycle thinking.

This thesis includes four individual case studies that all deal with different sustainability aspects and aim to measure, prioritize or communicate information about sustainability impacts of products and technologies. Common aspects in the case studies include the use of analytic, quantitative research methods together with qualitative methods and data, and active stakeholder engagement. All case studies apply the principles of life cycle thinking, considering how the information created from the assessment should be communicated and used in order to minimize evaluated impacts or to prioritize future activities.

The results from this study indicate that sustainability assessment methods are useful for generating information and increasing knowledge about the studied system and related sustainability impacts. Thus, they could be used to address some of the shortcomings related to lacking environmental information in sustainability management research. Analytic methods are important for sustainability assessment, since their use makes it necessary to consider in detail all related issues (inputs, outputs, life cycle phases and actors along the life cycle). However, due to many choices that have to be made during the assessment, the results become (at least partly) socially constructed. This does not reduce the value of the assessments, but increases the need for transparency when communicating the results. In future, more discussion about social aspects related to knowledge production and interpretation in the context of analytic methods is encouraged.

Sustainability assessment has been criticized for focusing too much on comparing existing alternatives, instead of considering if the evaluated options could

really contribute to sustainability. In addition, the focus of the field has been on the development of more precise methods and tools, rather than considering, how the methods could be used to support decision-making. In future, management theories could be applied in the context of sustainability assessment to increase understanding about the change processes that are required for implementing assessed activities, and considering, how the results should be presented to managers and other stakeholders.

Sustainability assessments may help in understanding the complexity that is related to sustainability, and identifying what needs to be changed or managed. However, both measuring and management require reductionism that makes complex issues easier to handle and to communicate. The study highlights how paradoxes and trade-offs are not only related to the concept of sustainability, but also on the many different methods that are applied for measuring it. Measuring is necessary for understanding sustainability challenges, but measuring is not enough to make sustainability manageable. It is argued that many of the existing challenges related to sustainability management cannot be addressed simply by developing more efficient metrics, but rather by increasing the understanding of the assessment process, and the kind of information the assessments are able to produce.

Practice-oriented transdisciplinary research provides a framework that allows combining methods and approaches that originate from different disciplinary practices. It acknowledges the paradoxes that are evident in both sustainability management and sustainability assessment. The study concludes that existing methods are useful for identifying trade-offs related to sustainability, but it is necessary to understand their limitations. Simply looking at measurable aspects may provide too narrow understanding of many sustainability impacts, and may hide important interlinkages, trade-offs and rebound effects. By extending the scope of the assessment from purely quantitative to more qualitative means, it is possible to increase understanding of the studied problem. At the same time, information becomes more fragmented and less specific, and more difficult to communicate. Consequently, one of the main challenges in sustainability assessment relates to balancing between comprehensiveness and simplicity of produced information. The more comprehensive the assessment is, the more difficult it is to provide simple guidelines. Yet many stakeholders would prefer to have simple guidelines about most sustainable options. It is proposed that future studies should focus on considering how organizations and individual decision-makers are able to use produced sustainability information for making more sustainable choices.

KEYWORDS: sustainability management, sustainability assessment, life cycle thinking, life cycle assessment, multicriteria decision-making, transdisciplinary research, sustainability science, paradox, trade-off

TURUN YLIOPISTO
Turun kauppakorkeakoulu
Johtamisen ja yrittäjyyden laitos
Johtaminen ja organisointi
HANNA PIHKOLA: Jos sen voi mitata, voiko sitä voi myös johtaa?
Poikkitieteellinen tutkimus kestävän kehityksen arvioinnista ja johtamisesta
Väitöskirja, 90 s. (+ alkuperäiset artikkelit)
Turun kauppakorkeakoulun tohtoriohjelma
Tammikuu 2021

TIIVISTELMÄ

Ympäristötiedon ja sopivien mittareiden puute on yksi kestävän kehityksen johtamiseen liittyvistä haasteista. Johtamisen ja organisoinnin tutkimusta on kritisoitu siitä, että se on keskittynyt lähinnä kestävän kehityksen taloudellisiin, sosiaalisiin ja organisatorisiin näkökulmiin ja jättää ympäristövaikutukset vähemmälle huomiolle. Tämä tutkimus pyrkii tuomaan uutta tietoa ja lisäämään ymmärrystä niistä monista käytännön haasteista, joita kestävän kehityksen arvioimiseen ja mittaamiseen sekä mittaustulosten viestintään liittyy. Aihe on tärkeä, sillä erilaisilla mittareilla ja tunnusluvuilla on keskeinen rooli kestävän kehityksen johtamisessa.

Poikkitieteellisen tutkimuksen periaatteiden mukaisesti tutkimuksessa on hyödynnetty menetelmiä, jotka on kehitetty insinööritieteiden ja teollisen ekologian aloilla. Tulokset ja johtopäätökset perustuvat käytännönläheisiin tapaustutkimuksiin, jotka kuuluvat kestävän kehityksen arvioinnin alaan. Tutkimus keskittyy erityisesti tuotekohtaisiin ja elinkaaripohjaisiin arviointimenetelmiin sekä elinkaariajattelun soveltamiseen arvioinnissa ja johtamisessa.

Tutkimus sisältää neljä yksittäistä tapaustutkimusta, joista jokainen käsittelee erilaisia kestävään kehitykseen liittyviä haasteita. Tapaustutkimusten tavoitteena on ollut erilaisiin tuotteisiin tai teknologioihin liittyvien vaikutusten mittaaminen tai niistä viestiminen sekä tarvittavien toimenpiteiden priorisointi. Kaikissa tutkimuksissa on sovellettu analyyttisiä, kvantitatiivisia tutkimusmenetelmiä yhdessä kvalitatiivisten menetelmien ja tietojen ja sidosryhmiltä kerättyjen palautteiden kanssa. Tapaustutkimuksissa sovelletaan elinkaariajattelun periaatteita ja pohditaan, kuinka arviointien avulla tuotettua tietoa voitaisiin hyödyntää joko tunnistettujen vaikutusten vähentämisessä tai keskeisten toimenpiteiden priorisoinnissa.

Tutkimuksen tulokset osoittavat, että kestävän kehityksen arviointimenetelmät ovat hyödyllisiä kestävyystiedon tuottamisessa sekä tarkasteltavien tuotesysteemien että niiden aiheuttamien ympäristövaikutusten kuvaamisessa. Näitä arviointimenetelmiä voitaisiin jatkossa hyödyntää enemmän myös johtamisen tutkimuksessa. Arviointien avulla voitaisiin kerätä erityisesti organisaatioiden toimintaan liittyvää ympäristötietoa, jonka on osoitettu puuttuvan useista johtamisen alan tutkimuksista.

Analyyttisillä menetelmillä on tärkeä rooli kestävän kehityksen arvioinnissa, sillä niiden soveltaminen edellyttää kaikkien tuotesysteemiin kuuluvien tekijöiden selvittämistä ja tarkkaa läpikäyntiä. Toisaalta arviointien suorittaminen edellyttää myös monenlaisten valintojen tekemistä. Niiden seurauksena tuotettu tieto on (ainakin osittain) sosiaalisesti rakentunutta. Tämä ei vähennä arviointien hyödyllisyyttä, mutta korostaa läpinäkyvyyden tarvetta tuloksia raportoitaessa. Tutkimustiedon sosiaalisesta rakentumisesta tulisikin jatkossa keskustella entistä enemmän myös analyyttisten menetelmien yhteydessä.

Kestävän kehityksen arviointia on kritisoitu keskittymisestä lähinnä arvioitujen vaihtoehtojen väliseen vertailuun kestävän kehityksen suoranaisen edistämisen sijaan. Alan keskeisenä painopisteenä on ollut entistä tarkempien ja kokonaisvaltaisempien menetelmien ja mittareiden kehitys. Tuotetun tiedon parempaan hyödyntämiseen ja viestintään erilaisissa päätöksentekotilanteissa on kiinnitetty huomattavasti vähemmän huomiota. Tulevaisuudessa johtamisen teorioita voitaisiin hyödyntää arviointien yhteydessä erityisesti niiden muutosprosessien analysoinnissa, joita tutkittujen tuotteiden tai teknologioiden käyttöönotto edellyttäisi. Lisäksi johtamisen näkökulmia voitaisiin hyödyntää, kun pohditaan, miten arviointitulokset olisi parasta esittää yritysjohtajille ja muille sidosryhmien edustajille.

Parhaimmillaan arvioinnit auttavat tunnistamaan asioita, joita pitäisi yrittää muuttaa ja joiden johtamisen tulisi kiinnittää enemmän huomiota. Sekä mittaaminen että johtaminen edellyttävät kuitenkin useita yksinkertaistuksia, jotta asioista tulisi helpommin käsiteltäviä ja viestittäviä. Tärkeitä näkökulmia voi jäädä arviointien ulkopuolelle, jos kaikkia tarpeellisia tietoja ei syystä tai toisesta ole voitu sisällyttää laskelmiin. Johtamisen näkökulmasta olisi siis olennaista ymmärtää, mitä voidaan mitata ja miten. Mutta vähintään yhtä tärkeää olisi ymmärtää, mitä ei voida mitata ja miksi.

Tutkimus osoittaa, että sen lisäksi, että kestävän kehityksen käsitteeseen liittyy erilaisia ristiriitoja ja jännitteitä, niitä liittyy myös sen mittaamiseen ja arviointiin. Vaikutusten arviointi on välttämätöntä, jotta kestävyyshaasteita opittaisiin ymmärtämään paremmin, mutta mittaaminen ei vielä tarkoita, että kestävä kehitys olisi johdettavissa. Tutkimus toteaa, että vaikka parempien mittareiden kehitystä on usein ehdotettu ratkaisuksi erilaisiin johtamisen haasteisiin, pelkkä mittareiden kehitys ei riitä ongelman ratkaisuksi. Sen sijaan meidän tulisi kiinnittää entistä enemmän huomiota sekä siihen, miten arviointeja tehdään, että siihen, minkälaista tietoa arviointien avulla on mahdollista tuottaa.

Tämän tutkimuksen perusteella käytännönläheinen poikkitieteellinen tutkimus mahdollistaa erilaisilta tieteenaloilta peräisin olevien menetelmien ja teorioiden yhdistelyn. Se hyväksyy ristiriidat, joita liittyy sekä kestävän kehityksen johtamiseen että arviointiin. Tutkimus toteaa, että olemassa olevat kestävän kehityksen arviointimenetelmät ovat hyödyllisiä ongelmakohtien ja ristiriitaisten valintatilanteiden tunnistamisessa, mutta on myös tärkeää ymmärtää menetelmiin sisältyvät rajoitteet. Jos keskitymme pelkästään mitattavaan tietoon, tutkimustulokset voivat jäädä liian kapeiksi, jolloin tärkeitä riippuvuussuhteita, takaisinkytkentöjä ja tehtyjä kompromisseja voi jäädä huomaamatta. Laajentamalla arviointeja puhtaasti mitattavista näkökulmista myös laadullisiin näkökulmiin voidaan saavuttaa kokonaisvaltaisempi käsitys tutkittavista ongelmista. Samalla kuitenkin tuotetusta tiedosta tulee vähemmän tarkkaa ja vaikeammin viestittävää. Usein arviointien tulosten toivotaan tuottavan selkeitä ja yksinkertaisia toimintaohjeita ja vaihtoehtoja. Haasteeksi kuitenkin muodostuu se, että mitä kokonaisvaltaisemmin kestävää kehitystä pyritään arvioimaan, sitä vaikeampi arvioinnin perusteella on antaa yksiselitteisiä toimintaohjeita. Jatkotutkimuksen tulisikin kiinnittää entistä enemmän huomiota siihen, miten yritykset ja yksittäiset päätöksentekijät voisivat paremmin ymmärtää ja hyödyntää arviointien avulla tuotettua tietoa.

ASIASANAT: kestävän kehityksen johtaminen, kestävän kehityksen arviointi, elinkaariajattelu, elinkaariarviointi, monikriteeripäätöksenteko, poikkitieteellinen tutkimus, kestävyystiede, ristiriita, vaihtokauppa

Acknowledgements

This thesis is a result of a long process, and I'm thankful for being able to work with so many great people throughout the years. First, I would like to thank my supervisor, Professor Tomi J. Kallio, who first taught me the basics of environmental management almost 20 years ago. Tomi encouraged me to become a researcher and provoked my interest in the diverse research field of organizations and the environment. Even if this process took much longer than first anticipated, he was always willing to provide support when I needed it. Thank you! My second supervisor, Dr Kirsi Liikamaa, joined the process in the last few years. I would like to thank Kirsi for her insightful and supportive comments, which were important to get this study finalised.

I would also like to express my thanks to my pre-examiners, Professor Lassi Linnanen and Professor of Practice Mikko Jalas. I appreciated the constructive feedback and the comments you provided during the pre-examination phase. The feedback helped me to improve this manuscript. Even if it was not possible to integrate everything in this study, I feel that your comments provided me with good ideas for potential future studies. I'm particularly thankful that Professor of Practice Mikko Jalas accepted acting as an opponent of this thesis.

This study would not have been possible without my colleagues and co-authors, from whom I have learned so much during our joint projects. So thank you Lauri Kujanpää, John Bacher, Maija Federley, Minna Nors, Eemeli Tsupari, Katri Behm, Helena Dahlbo, Sirkka Koskela, Matti Kojo, Mikko Hongisto, Olli Apilo, Mika Lasanen, Laura Sokka, Minna Nissilä, Jyri Seppälä and Ulla-Maija Mroueh for your cooperation and the many interesting discussions regarding these topics. Any potential mistakes in this synthesis are my own.

Over the years, I have worked with many great professionals, many of whom have become friends. It would be impossible to name all of you, but a special thanks goes out to all the members of our Suskis group. Especially Tiina Pajula, Helena Wessman-Jääskeläinen, Katri Behm, Catharina Hohenthal and Saija Vatanen, who have been among my closest colleagues for so many years. A special thanks also goes out to Lauri Kujanpää and John Bachér, with whom we have travelled around Europe to conduct MCDM workshops. With Minna Nors and Maija Federley, I got

to learn so many things related to print products and media. Thank you to all the current and past team members from VTT and the many colleagues from other research institutes, universities and companies I have had a chance to work with. I wanted to hand a finalised version of this thesis to my former VTT colleague, Petteri Kangas, who passed away suddenly and too young. Petteri supported me and acted as my mentor when I decided I would try to finalise my PhD studies.

The case studies included in this thesis have been conducted in research projects that have received funding from VTT (Case study I), from Tekes - the Finnish Funding Agency for Technology and Innovation (currently Business Finland) (Case study II) and from the European Commission (Case study III). Case study IV was conducted as part of a research project that received funding from several sources: the Finnish Funding Agency for Technology and Innovation, the Graphic Industry Research Foundation of Finland (GTTS), Metsäliitto Group, Myllykoski Corporation, Stora Enso Group and UPM-Kymmene Corporation. During the earlier years of my research career, I received research grants from Liikesivistysrahasto and Turun Kauppaseuran säätiö. The funding received from VTT was important for finalising this synthesis. Equally important was the flexibility in organising the study leaves that were necessary for writing this synthesis.

I would also like to thank the personnel of Turku School of Economics. Jenni Heervä and Jukka Tuominen have provided support in administrative issues. From the Department of Management and Entrepreneurship, I would especially like to thank Professor Satu Teerikangas. Satu's positive attitude and friendliness were important when I was still hesitant whether it would ever be possible to put together all the different pieces that were needed to finalise this process. I have always felt at home at the Turku School of Economics, and it was nice to be back to finalise this work that was originally started there so many years ago.

My friends and neighbours have helped in maintaining a positive spirit at times when this process felt too long and heavy. Hanna Gorshelnik, Hanna Kalliomäki and Salla Kaitokari provided much appreciated comments in editing the abstracts included in study. Thank you all!

Finally, the biggest thanks go to my family. Thank you Jussi, Frans and Selma for your love and patience during all the days, nights and holidays that were used in this process. Thanks to my mother and father for showing that it is possible to learn and to do many different things in life. And thanks to my sisters Minna and Jenni just for being there and providing help whenever needed.

Helsinki, 10th of January, 2021
Hanna Pihkola

Table of contents

Tables

Figures

List of Original Publications

This dissertation is based on the following original publications, which are referred to in the text by their Roman numerals:

I Pihkola Hanna, Hongisto Mikko, Apilo Olli and Lasanen Mika. Evaluating the energy consumption of mobile data transfer – From technology development to consumer behaviour and life cycle thinking. *Sustainability*, 2018; 10 (7), 2494; https://doi.org/10.3390/su10072494

II Pihkola Hanna, Tsupari Eemeli, Kojo Matti, Kujanpää Lauri, Nissilä Minna, Sokka Laura and Behm Katri. Integrated sustainability assessment of CCS – Identifying non-technical barriers and drivers for CCS implementation in Finland. *Energy Procedia*, 2017; 114: 7625–7637; https://doi.org/10.1016/j.egypro.2017.03.1895

III Bachér John, Pihkola Hanna, Kujanpää Lauri & Mroueh Ulla-Maija. Advancing the circular economy through group decision-making and stakeholder involvement. *Detritus: Multidisciplinary Journal for Waste Resources & Residues*, 2018; 4: 22–35; https://doi.org/10.31025/2611-4135/2018.13741

IV Dahlbo Helena, Koskela Sirkka, Pihkola Hanna, Nors Minna, Federley Maija & Seppälä Jyri. Comparison of different normalised LCIA results and their feasibility in communication. *International Journal of Life Cycle Assessment*, 2013; 18(4): 850–860; https://doi.org/10.1007/s11367-012-0498-4

1 Introduction

1.1 Background

Sustainable development has an established foundation as a policy objective in Europe and internationally (European Commission, 2016; United Nations, 2015). Achieving sustainable development would require solving the many challenges related to excessive use of resources, protecting the natural environment and providing food and livelihoods for the growing population (see e.g. Godfray et al., 2010; IPCC, 2018; IPBES, 2019). However, despite the popularity of sustainable development as a concept, current development is far from being sustainable.

According to the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), humans are currently extracting more resources from the planet than ever before. Total use of resources has doubled since 1980, partly due to increasing population, but also due to increase in per capita consumption levels (IPBES, 2019). Increasing use of resources is deteriorating natural habitats and one million species are in danger of becoming extinct (ibid).

The Global Sustainable Development Report 2019 highlights how resource use and human well-being continue to be distributed unevenly between people and regions (Independent Group of Scientists appointed by the Secretary-General, 2019). While the number of people living in extreme poverty has decreased (being 136 million in 2015), poverty is concentrated in certain regions and among marginalized groups (ibid). 1.3 billion people suffer from multiple forms of poverty that include lack of proper income, insufficient access to clean water and sanitation, poor health and low level of education (Independent Group of Scientists appointed by the Secretary-General, 2019).

A recent report compiled by the World Meteorology Organization (WMO) (2020) states that global greenhouse gas emissions have continued to increase, reaching all-time records in 2020. Despite years of climate negotiations, fossil greenhouse gas emissions have risen by 62% since 1990 (WMO, 2020). Rising temperature is threatening water security in large areas, and loss of biodiversity is endangering global food security (IPCC, 2018; WMO, 2020). According to the Intergovernmental Panel on Climate Change (IPCC), major transitions in energy, land and urban infrastructure and within industrial systems would be required in

order to cut greenhouse gas emissions, and to prevent the most serious impacts of climate change (IPCC, 2018). In addition to system-level changes, changes in individual consumption habits would be urgently required (WMO, 2020). However, even if knowledge related to various sustainability challenges is increasing there is "relatively limited scientific knowledge on how to achieve transformations to sustainable development" (Independent Group of Scientists appointed by the Secretary-General, 2019, p. 121).

As a response to the challenge of solving global environmental and social problems, sustainability science or sciences of sustainability are emerging as new fields of academic research. One of the first definitions of sustainability science was presented by Kates et al. (2001). According to their projections, research in the field of sustainability science should be focused on

> "the character of nature-society interactions, on our ability to guide those interactions along sustainable trajectories, and on ways of promoting the social learning that will be necessary to navigate the transition to sustainability" (Kates et al., 2001, p. 642).

Essential elements of sustainability are interactions between industrial and ecological systems and therefore studying each system independently is not adequate (Seager, 2008). A key aspect of sustainability science is the orientation towards problem solving (Sala, Ciuffo and Nijkamp, 2015), which often requires a combination of different research methods and knowhow from several disciplines, connected with knowledge from current practices that need to be changed (see e.g. Lang et al., 2012). A crosscutting theme within this interdisciplinary research area is the integrated management of human, social and biological systems (Bettencourt & Kaur, 2011).

Sustainability science differentiates from traditional science, since it is use-inspired, has a strong focus on applied knowledge and is committed to moving created knowledge into societal action (Kates, 2011). Sustainability science has been inspired by the concepts of post-normal science and mode-2 science (Funtowicz & Ravetz, 1993; Robert W. Kates et al., 2001; Kemp & Martens, 2007). According to Lang et al. (2012), need for these new science paradigms is motivated by the need to use participatory approaches for integrating knowledge from scientists, stakeholders, advocates, active citizens and users of knowledge. Addressing the complex sustainability problems requires that constructive input from all relevant disciplines and actor groups is integrated (ibid). Lang et al. (2012, p. 26) define transdisciplinarity as follows:

> "Transdisciplinarity is a reflexive, integrative, method-driven scientific principle aiming at the solution or transition of societal problems and concurrently of related scientific problems by differentiating and integrating knowledge from various scientific and societal bodies of knowledge".

In addition to the field of sustainability science, the need for cooperation and integration between different disciplines and theoretical approaches has been emphasized by several management and responsibility scholars (Bansal & Gao, 2006; Gladwin, Kennelly, & Krause, 1995; Hahn, Figge, Aragón-Correa, & Sharma, 2017; Montiel & Delgado-Ceballos, 2014; Starik & Kanashiro, 2013; Williams, Kennedy, Philipp, & Whiteman, 2017). Already in 1995, Gladwin et al. (1995, p. 897) emphasized that "the idea of sustainable development pushes management research towards interdisciplinary and *transdisciplinary* modes of inquiry" and perhaps, ultimately, "toward the realm of post-normal science".

Lately, the need for transdisciplinary research approaches and cooperation between researchers from different disciplines has been readdressed (Bansal, 2019; Ergene, Banerjee, & Hoffman, 2020; Schaltegger, Beckmann, & Hansen, 2013; Shrivastava, Ivanaj, & Persson, 2013), but it seems that transdisciplinary studies in sustainability management and corporate responsibility are still rare (Isil & Hernke, 2017). Due to the complexity, urgency and seriousness of the sustainability challenges that all organizations are facing, it is necessary that sustainability management broadens its scope and actively seeks to incorporate knowledge from other disciplines and practitioners (Starik & Kanashiro, 2013). This study aims to address this gap by using a transdisciplinary research approach that combines methods and approaches developed in the field of sustainability assessment, and considers their applicability for sustainability management.

1.2 Motivation for the study and research gap

The interconnectedness of organizations and the natural environment, and the importance of living within the ecological boundaries of our planet was highlighted in the early days of sustainability management research (Gladwin et al., 1995; Jennings & Zandbergen, 1995; Shrivastava, 1995b; Starik & Rands, 1995). However, at the same time it was already clear that operationalizing and measuring sustainability of organizations would be a challenging task (Gladwin et al., 1995; Starik & Rands, 1995). The need for appropriate sustainability measures, feedback mechanisms, practical decision-support tools and sustainability indicators was highlighted (Gladwin et al., 1995; Jennings & Zandbergen, 1995; Shrivastava, 1995b; Starik & Rands, 1995). According to Shrivastava (1995), the conceptual

fuzziness of the area was compounded by the lack of good measures of organizational sustainability.

Since 1995 and the publication of the *Academy of Management Review's* special issue on ecologically sustainable organizations, research related to corporate sustainability and responsibility has increased in volume and matured (Bansal & Gao, 2006; Hahn et al., 2017; Linnenluecke & Griffiths, 2013; Montiel & Delgado-Ceballos, 2014). Nonetheless, questions regarding both measurement and management of sustainability seem far from being solved (See e.g. Delmas, Etzion and Nairn-Birch, 2013; Montiel and Delgado-Ceballos, 2014; Boiral and Henri, 2017; Mura et al., 2018).

While research in corporate sustainability has greatly advanced during the years, it seems that measuring sustainability is still a challenging topic for sustainability management. A recent review study by Mura et al. (2018) highlights, how academic literature on sustainability measurement has grown exponentially since 1992. However, due to cross-disciplinary nature of the topic and several research communities studying different aspects, a comprehensive overview and conceptualization of sustainability measurement is currently lacking (Mura et al., 2018). In another review study, Montiel-Delgado and Ceballos (2014) noted that corporate sustainability has been measured in many different ways, and there is no standard way of measuring corporate sustainability. Majority of the corporate sustainability studies rely on existing sustainability indices or rating systems (such as the Dow Jones Sustainability Index, and GRI sustainability-reporting framework) and secondary data sources (Montiel & Delgado-Ceballos, 2014).

When turning the focus from academic studies to more practice-oriented literature related to sustainability measurement, the amount of available measures, tools and guidelines becomes multiplied, as sustainability assessment in its different forms is a growing field of research and consultancy services. Discussions with industrial sustainability experts and managers reveal how companies are struggling with the large number of available assessment methods and indicators, many of which are not compatible with each other, nor are flexible enough to meet the many information needs of both internal and external stakeholders (Pihkola et al., 2017). Despite existence of several sustainability standards and reporting frameworks, even the standardised methods suffer from challenges related to comparability of produced information (Boiral & Henri, 2017).

One of the practical challenges relates to incompatibility and incomparability of different metrics and indicators, which makes building a comprehensive overview of different sustainability aspects challenging. Addressing different sustainability dimensions usually requires application of many different assessment methods. More the indicators added, more complex the results may become. Thus, it could be argued that currently the problem is not so much with the existence of proper

measures, but the existence of so many measures and their interpretation. Or more importantly, even if we have all these measures and information available, why is the state of the natural environment still getting worse?

Lately, the "big disconnect between sustainable business and sustainable development" (Dyllick & Muff, 2016, p. 157), has re-gained attention within management and organization studies. Despite the mainstreaming of many sustainability-related practices in business organizations, the state of the natural environment is deteriorating rapidly (Bansal, 2019; Dyllick & Muff, 2016; Ergene et al., 2020; IPBES, 2019; IPCC, 2018). Academic corporate responsibility and sustainability management research has been criticized for failing to inform management practices about sustainable development (Montiel & Delgado-Ceballos, 2014). Starik and Kanashiro (2013) argue that current management theories do not adequately focus on the impacts of our decisions and actions on the natural environment, nor on the interconnectedness of environmental and social systems.

In their bibliometric analysis of over 3000 articles, Linnenluecke and Griffiths (2013) conclude that corporate sustainability research has remained disconnected from the wider political and societal debates concerning climate change and resource scarcity. Additionally, there is little cross-referencing to other disciplines, such as the natural sciences (Linnenluecke & Griffiths, 2013). Winn and Pogutz (2013) argue that while business organizations are progressing and taking important steps in ecosystem service management, nature and nature's functioning have not yet been sufficiently integrated into organization and natural environment literature.

Business studies have been accused of being too focused on understanding the social, organizational, or institutional implications of corporate sustainability, and forgetting about the ecological impacts of their activities (Kallio & Nordberg, 2006; Whiteman, Walker, & Perego, 2013). Lack of environmental data has been acknowledged as one of the major shortcomings restricting the scope of the studies and the environmental aspects that can be considered (Etzion, 2007). Consequently, many corporate sustainability studies rely on secondary data sources when evaluating sustainability performance (Montiel & Delgado-Ceballos, 2014).

Dyllick and Muff (2016) state that even if the early works of authors such as Gladwin et al. (1995) and Shrivastava (1994; 1995b) were addressing the link between sustainable development at the societal level, and business activities at the organizational or operational level, the focus on sustainable development as a societal goal was later forgotten from the business sustainability discourse. Ergene et al. (2020) describe how research in organizations and the environment has been divided in two different epistemological perspectives: critical and managerial. While the critical works highlighted that the economic focus of management and organization studies prevented true consideration of ecological aspects, the

managerial perspective focused on integrating environmental concerns within existing theoretical frames and managerial practices (Ergene et al., 2020).

Within the managerial perspective, as defined by Ergene et al. (2020), a large part of research efforts was dedicated in studying potential win-win solutions, in which both environmental and economic gains could be achieved simultaneously (see also, Hahn, Figge, Pinkse, & Preuss, 2010). Majority of corporate sustainability research has followed an instrumental logic, according to which the economic dimension was prioritized over environmental and social dimensions (Hahn et al., 2010). According to the instrumental logic, which is compatible with the win-win paradigm, environmental and social aspects were only considered in case they were in line with or were contributing to firm's economic performance. Consequently, most of the research activities have been focused on how social responsibility benefits the company while the impacts of those activities to the society have been much less considered (Margolis & Walsh, 2003). Potential conflicts and trade-offs within and between different sustainability aspects were largely ignored (Hahn et al., 2010; Hahn, Pinkse, Preuss, & Figge, 2015).

Lately, several management scholars have re-questioned whether it is possible to achieve business sustainability with existing measures, and called for more radical approaches for sustainability management (Dyllick & Muff, 2016; Starik & Kanashiro, 2013). Critics argue that the focus of action and research alike should be changed from incremental improvements towards radical changes within the dominating business logic (Ergene et al., 2020). Within their typology, Dyllick and Muff (2016) describe four alternative approaches to business sustainability, according to the ability and relevance of each approach to contribute in solving existing sustainability challenges. They start their typology from "business-as-usual", in which the main interest of business is purely economic. While the first three levels (Business-as-usual, Business sustainability 1.0 & Business sustainability 2.0) could possibly be integrated within the managerial perspective as described by Ergene et al. (2020), the fourth level of business sustainability (Sustainability 3.0, true sustainability) is perhaps somewhat close to what Ergene et al. (2020) call "the ecological case for business". These ambitious approaches seem to share many similarities with the ecocentric (Shrivastava, 1995a) and sustain-centric (Gladwin et al., 1995) paradigms that were first discussed 25 years ago. A common factor for all these approaches is related to using a systems approach instead of a linear approach, questioning the dominance of economic values over environmental and social ones, and re-thinking the role that companies play in the society.

According to Dyllick and Muff (2016), responding to sustainability challenges is only possible if companies redefine their role completely. Instead of creating value to shareholders and stakeholders, the role of companies should be focused at contributing towards the common good and solving the global social and

environmental challenges. From measurement point of view, this would require moving from minimizing negative impacts to maximizing positive impacts to the society and the environment. While the change towards true business sustainability would require a profound change in values, the critical role of sustainability measurement becomes evident again. When considering what is required in a move towards Sustainability 3.0 (or so-called true sustainability) Dyllick and Muff (2016) highlight the need to develop activities related to both transparency and metrics:

> "an effective assessment of the business contributions to sustainability issues requires adequate metrics and measures to assess and compare their impact. In this field, more work is required to come up with issue-specific metrics that reliably indicate improvements". (Dyllick & Muff, 2016, p. 170)

Thus, taking into account the important role that measurements have for management purposes, it is important to consider the many challenges related to conducting such measurements. This includes questioning to what extent it is actually possible to measure sustainability. And is sustainability performance really comparable? The above cited literature highlights, how measuring sustainability and integrating environmental information in management studies are continuous challenges for sustainability management scholars. Whether the focus is on positive or negative impacts, the main challenges related to measuring sustainability remain the same. These challenges are equally faced by the many sustainability assessment practitioners and experts who struggle in communicating assessment results to top managers and decision-makers, who often prefer to hear simple answers, presented as one figure or graph.

1.3 Aim of the study

The aim of this study is to consider the ability of sustainability assessment methods to provide the metrics and the knowledge that would be necessary for the purposes of sustainability management. The study shows how sustainability assessment methods can be used to collect environmental information, measure environmental performance and to create the necessary feedback loops between the social and natural environments in which the companies operate. However, it also highlights the limitations and drawbacks that are present in most assessments. It aims to critically evaluate the ability of existing methods to assess and to reveal tensions and trade-offs, and increase understanding of current sustainability challenges.

In this study, it is considered that understanding the many complexities related to sustainability is a necessary first step for sustainability management. The study aims to increase understanding of the ability of different assessment methods to

provide (measurable) sustainability information that is often considered necessary for management purposes. Thus, it addresses some of the fundamental challenges related to sustainability management. According to principles of transdisciplinary research, it uses methods that have been developed in the fields of engineering and industrial ecology, and builds on case studies that originate from the practice-oriented field of sustainability assessment.

An overarching theme in this thesis is life cycle thinking, as it is considered that life cycle thinking is necessary both in sustainability assessment and in sustainability management. According to the UNEP/SETAC Life cycle initiative, "Life cycle thinking is about getting reliable information about environmental, social and economic impacts into people's hands at the time they are making decisions" (UNEP, 2012). Life cycle thinking exceeds organizational boundaries and takes into account the environmental, economic and social impacts of products over their whole life cycle, from raw material acquisition until recycling or disposal (UNEP, 2012).

Life cycle assessment (LCA) is a central method in life cycle thinking. LCA is a quantitative assessment method that can be used for modelling the life cycle of a product, and for measuring all inputs and outputs that take place within a product system (ISO 14040, 2006). In addition, it may be used for connecting these inputs and outputs to different environmental impacts using specific characterization factors (ibid). LCA is commonly applied by different industrial sectors for measuring environmental impacts of products, and its use is recommended by the European Commission (Pihkola et al., 2017). Use of LCA is incorporated in many European policies (Sonnemann et al., 2018), but studies addressing the organizational and managerial aspects related to use of these methods (Rex & Baumann, 2008), and the applicability for management and policy support are still rare (Fullana i Palmer et al., 2011).

Life cycle thinking and life cycle management are two closely linked research fields, and sometimes it is difficult to make a distinction between them. Both fields highlight the importance of the life cycle view in corporate environmental and sustainability activities. According to the life cycle view, it is necessary to look beyond organizational boundaries when studying the environmental impacts of products. While life cycle management is interested in how life cycle activities are organized and managed in companies, life cycle thinking focuses on practices related to LCA and life cycle management, and has an emphasis on social science research (Nilsson-Lindén, Baumann, Rosén, & Diedrich, 2018). Thus, life cycle thinking shares similarities with organization studies, and organization theories have been applied in studies focusing on life cycle thinking (See e.g. the work by Heiskanen, 2000 and Rex & Baumann, 2008).

Within management and organization studies, LCA has been identified as a potential method for sustainability management, providing information about the input and output flows that take place between organizations and the natural environment (See e.g. Gladwin, Kennelly and Krause, 1995; Hart, 1995; Jennings and Zandbergen, 1995; Shrivastava, 1995; Starik and Rands, 1995). However, it seems that LCA and other sustainability assessment methods have rarely been used by management scholars when measuring sustainability performance (cf. Montiel and Delgado-Ceballos, 2014; Mura et al., 2018), and the studies related to environmental and social systems have remained separated (Hoffman, 2003; Korhonen, von Malmborg, Strachan, & Ehrenfeld, 2004; Rex & Baumann, 2008). In addition, even if dedicated streams of literature have focused on green supply chain management and cooperation between companies and their stakeholders, most management studies still focus on individual companies when evaluating sustainability performance (see, e.g., Mura et al., 2018; Searcy, 2016). From life cycle point of view, this is not adequate for evaluating or understanding sustainability impacts, as most companies are dependent on raw materials, energy, logistics and other services that take place outside their own borders.

In this study, it is proposed that the two research fields, namely sustainability assessment and sustainability management would benefit from cooperation and integration of theories and research approaches. Life cycle thinking is a small but developing research field that combines aspects from both sustainability assessment and sustainability management. In this study, it is considered that life cycle thinking could be used as kind of a bridge between the two fields that address similar challenges, but use different methods and theories to do so. According to principles of life cycle thinking, it is also necessary to question and to consider how we can measure different aspects of sustainability? And secondly, how should and could (environmental, economic or social) sustainability information be interpreted and used for decision-making and management purposes, in order to promote transition towards sustainability?

1.4 Research questions

The study aims to respond to the following two research questions:

I. What are the interlinkages between sustainability management, sustainability assessment and life cycle thinking?

II. Can sustainability assessment increase understanding about potential trade-offs related to sustainability management?

The study is structured as follows: Chapter 1 presents the background and motivation for the study, describes the research gap that this study aims to address and defines

the research questions. Chapter 2 presents the principles of transdisciplinary research and explains how transdisciplinarity was defined and applied in this study. In addition, it considers transdisciplinarity from the point of view of management and organization studies. Even if transdisciplinarity is gaining popularity in sustainability science, it is still not very common in management and organization studies (Bansal, 2019; Ergene et al., 2020). Chapter 3 presents the theoretical framework used in this study. The framework consists of short introductions of the key theories, assumptions and methods used in the research fields of sustainability management, sustainability assessment and life cycle thinking.

Chapter 4 presents the main findings from the case studies. The chapter describes what kind of challenges are faced when conducting sustainability assessments in practice. Many of these challenges relate to topics that are commonly addressed within management and organization studies. Chapter 5 presents the main conclusions and findings from the study, and proposes topics for future research. The chapter describes the assumed benefits that could be achieved by better integration of theories and practices related to sustainability management and assessment. Finally, this study aims to provide recommendations that would be relevant to both research and practice related to sustainability assessment and management. Additionally, it discusses some of the common challenges related to transdisciplinary research, namely integration, reflection, paradox and evaluation (according to Wickson, Carew and Russell, 2006), as faced in the context of this thesis.

The research questions and the main responding sections are summarized in Table 1. Depending on the research question, this study includes exploratory, descriptive and integrative elements.

Table 1. Research questions and main responding sections of the study

Type of study	Research question	Main responding section
Exploratory	1. What are the interlinkages between sustainability management, sustainability assessment and life cycle thinking?	Introduction, Theoretical framework, Case studies
Descriptive, Integrative	2. Can sustainability assessment increase understanding about potential trade-offs related to sustainability management?	Case study results & Conclusions

2 Research approach

2.1 Principles of transdisciplinary research

This study applies a transdisciplinary research approach (Hirsch Hadorn et al., 2008; Lang et al., 2012; Wickson et al., 2006) in which the aim is to integrate knowledge from different fields, and create useful outcomes for both theory and practice. According to Wickson et al. (2006) it is not always easy to make a distinction between transdisciplinary, multidisciplinary and interdisciplinary research, but the three approaches differ in their level of integration. In interdisciplinary research, researchers representing different disciplines work together in a coordinated manner, but each researcher applies her or his own epistemological approaches, and/or studies different aspects of the same research problem (Pohl & Hirsch Hadorn, 2008; Wickson et al., 2006). In multidisciplinary research, different disciplinary methods and approaches are used, but in an unintegrated manner, and with only little or no synergies in the outcomes (ibid). Transdisciplinary research aims at integration of different disciplinary methodologies and epistemologies, in studying a joint research problem, and creating synergy in the outcomes (See Wickson et al. 2006; Lang et al. 2012).

This study is inductive in nature and applies a case study approach. According to the definition presented by Yin (1994, p.13),

> "a case study is an empirical inquiry that investigates a contemporary phenomenon within its real-life context, especially when the boundaries between the phenomenon and context are not clearly evident".

The case definition by Yin (1994) fits well with the sustainability assessment case studies included in this thesis, and to the transdisciplinary research approach in general, as sustainability problems are always tightly related to the context in which they are studied. However, Yin (1994, p. 8) also describes case studies as the preferred strategy for studying contemporary events "when the relevant behaviours cannot be manipulated". By contrast, in transdisciplinary research and within sustainability science, a researcher is an active participant in the research process, rather than a neutral, external observer. According to the definition of sustainability

science, researchers should be actively "promoting the social learning that will be necessary to navigate the transition to sustainability " (Kates et al., 2001, p.642). The approach used in this study is different from the traditional view of science, as sustainability science and transdisciplinary research are inspired by the idea of post-normal science. In post-normal science, "uncertainty is not banished, but is managed, and values are not presupposed, but are made explicit"(Funtowicz & Ravetz, 1993, p. 740).

This thesis includes four individual case studies that all deal with different sustainability aspects and aim to measure, prioritize or communicate information about sustainability impacts of products and technologies. According to the inductive research logic, the starting point of this study is the case studies and their findings, together with the experiences of the author. However, these practice-oriented findings have been used for framing a research problem that is also scientifically interesting and relevant (See Lang et al., 2012).

Specific characteristics of transdisciplinary research include *problem focus, evolving methodology and extensive collaboration* (Wickson et al., 2006). According to Wickson et al. (2006), *problem focus* relates to focusing on so-called 'real-world' problems, since the aim of the study is often to provide solutions to practical problems, and thus initiate change. In the context of transdisciplinary research, *evolving methodology* means that applied methods and approaches continue to develop over the course of the project, responding to the learning and changing perspectives of the stakeholders participating in the research (ibid).

Another essential element of transdisciplinarity is fusion of knowledge generated using different disciplines, and knowledge generation together with the community (Lang et al., 2012; Wickson et al., 2006). Thus *collaboration* in transdisciplinary research includes both collaboration with the broader community and collaboration between researchers representing different disciplines (Lang et al., 2012). All case studies included in this study have been conducted together with researchers that have different disciplinary backgrounds. The original research problems have been defined together with industrial actors and other stakeholders who participated in the studies.

2.2 Transdisciplinarity in management and organization studies

Central elements in transdisciplinary research are integration of different disciplinary approaches and focus on real-life problems. Both elements are central also within management and organization studies. According to Pfeffer (1997) organization studies as a research field is characterized by its interdisciplinary nature, and its close relation with applied science (See also Scott, 1998).

Organization studies has included elements from the fields of engineering, psychology, sociology, economics, law and even ecology (See e.g. Pfeffer, 1997; Scott, 1998; Williamson, 1990). Pfeffer (1997, p. 4.) argues that the interdisciplinarity of organization studies "makes cross-level analysis and the advance of theory more likely through processes of cross-fertilization". However, due to the diversity related to potential methods and theoretical perspectives that can be included within the scope of organization studies, integration of knowledge within the field has become challenging (ibid). Diversity within the field has led to development of several competing and conflicting paradigms that contribute to development of the field but also increase its fragmentation (Pfeffer, 1997). A large diversity of applied definitions, approaches, methods and areas of study is also characteristic for the evolving fields of sustainability management and corporate sustainability (Hahn et al., 2017; Montiel & Delgado-Ceballos, 2014; Mura et al., 2018).

However, it seems that some of the basic beliefs related to superiority of economic values, anthropocentric ethics and modernistic and positivist interpretations of organizations are deeply rooted within organizational research that is focused on sustainability (Ergene et al., 2020; Gladwin et al., 1995; Margolis & Walsh, 2003; Shrivastava, 1995a). Shrivastava (1994) described how the traditional organization theories have almost completely ignored the natural environment, or considered it purely as a resource that can be exploited for gaining competitive advantage or economic gains. Even the systems theory that highlighted the interdependence of the organizations with its environment has mainly focused on economic and social aspects and often ignored the natural environment (Shrivastava, 1994).

Gladwin et al., (1995) stated that the idea of sustainability requires organization theories to acknowledge the systemic interconnection between organizations and the natural environment. This view would consider the full range of material and physical exchanges between the organizations and the biosphere, and accept that organizations are both causing and being affected by environmental problems, such as climate change or loss of biodiversity (Gladwin et al., 1995). Shrivastava (1994, p. 713), claimed that "the positivist tendencies in OS[1] place heavy emphasis on measuring organizational environments objectively". However, he continues by stating that while such measurements may increase precision, they also reduce the descriptive richness related to the topics (Shrivastava, 1994). This reductionism relates to the need to simplify inherently complex things, in order to make them measurable.

[1] OS=organization studies

While the critiques presented by Shrivastava (1994) and Gladwin et al. (1995) were published already 25 years ago, it seems that many of these topics are still valid today. More recently, the narrow disciplinary background (lack of environmental and physical sciences) and lack of feedback loops between the environmental and the social environments has been recognized as one of the development needs in the field of sustainability management (Ergene et al., 2020; Starik & Kanashiro, 2013). Ergene et al. (2020, p. 5) have claimed that the current analytical tools for corporate sustainability "do not capture the contradictions of market-based ideals and socio-ecological wellbeing, and therefore reproduce the illusion that we can pursue unlimited economic growth while managing the natural environment and creating equitable societies".

Within the field of environmental management, Welford (1998) has called for a critical research agenda for environmental and technological management. Welford's critical research agenda questions the traditional, modernist views of organizations and society. It combines both interpretivist and positivist approaches, and considers that neither of them is sufficient alone. Welford (1998, p. 9) argues that:

> "From a critical perspective it is not possible to separate the social organization of knowledge production from the knowledge itself".

The critical research agenda focuses on problem identification and problem solving, with the ultimate aim of creating change (Welford, 1998). As a consequence, a strong applied and practical focus is necessary (ibid). Thus, the critical research approach proposed by Welford (1998) is very close to the idea of transdisciplinary research, as described above.

The epistemological tensions related to the need to measure something that is observable in nature, but becomes socially constructed in an organizational context, have been recognized in the context of management studies. Gladwin et al. (1995, p. 877) addressed this by stating that:

> "Scholars dealing with sustainability, we believe, must accept the interpenetration of observable fact and humanly assigned value, the hazy lines between description and prescription, and the twin filters of scientific viability and policy usefulness inherent in this value-laden topic".

Similarly, Jennings and Zandbergen (1995, p. 1042) state that even if, according to institutional theory, sustainable development is considered as a socially constructed concept, it is not possible to forget about its environmental basis (which acts as technical bounds to the meaning):

> "People are not free to consider sustainability just anything and, at the same time, hope that the term will have some attachment to the functioning of the ecological system within the biosphere".

In practice, this means that we can use natural sciences and engineering tools to get information from the state of the environment, and we may use many technologies and models for calculating how many emissions are created per one ton of product. However, society (consisting of organizations and individuals) needs to decide when these emissions become problematic and when our actions become unsustainable. In practice, poor comparability of sustainability information together with lack of exact definitions and limits for both sustainable and unsustainable behaviour at the organizational level leave a lot of room for interpretation.

In sustainability science, "combining different ways of knowing and learning" is necessary, so that different actors can cooperate in situations that include uncertainty and limited information (Kates et al., 2001, p. 641). This study aims to consider and combine both *positivist* and *interpretive* approaches (see Dijk et al., 2017), and argues that both are necessary when working at the interface of sustainability assessment and management. These kinds of combinations are typical for studies related to life cycle thinking, since they are usually interested in combing aspects from both engineering and social sciences (See e.g. Heiskanen, 2002; Rex & Baumann, 2008).

From the perspective of organization studies, this study can be characterized as phenomena-driven (fact-centred) as described by Montiel and Delgado-Ceballos, (2014), since it does not apply any of the traditional organization theories that are commonly used in corporate sustainability research, but describes facts and case studies and draws conclusions from the observed phenomena. The observed phenomenon in this case is life cycle thinking in the context of sustainability assessment and management.

2.3 Paradoxes and trade-offs in sustainability measurement and management

This study takes an integrative view of corporate sustainability (Hahn et al., 2015), recognizing that sustainability includes environmental, economic and social aspects, and accepts the existence of paradoxes within the concept. In addition, it acknowledges the existence of trade-offs between different aspects of sustainability. In this study, it is considered that existence of paradoxes is a central element in all sustainability-related research. Even if the goal of sustainable development is a balance between environmental, economic and social development, it is not very common to find solutions that would be equally beneficial in all three of them.

Corporate sustainability research has only recently started to address these tensions, recognizing that it is often not possible to be sustainable if all dimensions (environmental, economic and social) are considered (Hahn et al., 2015).

The integrative view questions the ideal of being sustainable in all dimensions at once due to the inherent tensions within the concept of sustainability (Hahn et al., 2010; Hahn, Preuss, Pinkse, & Figge, 2014). According to the integrative view of corporate sustainability, managers need to accept tensions between conflicting sustainability aspects, rather than ignore them. Trade-offs in corporate sustainability are situations in which contributions towards sustainability can only be achieved if one accepts a compromise between the sustainability aspects that are in conflict with each other (Hahn et al., 2010). In practice, this could mean accepting lower performance in one sustainability dimension in order to achieve higher performance in another.

However, focusing on trade-offs may also lead to a situation in which these trade-offs are handled by forcing a choice between the different aspects (Van der Byl & Slawinski, 2015). Using the organizational theory of the paradox (Smith & Lewis, 2011), Van der Byl and Slawinski (2015) argue that this is not a fruitful way to address tensions related to sustainability, as the same tension will soon need to be addressed again. They suggest that in a forced situation of choice, most companies would end up choosing economic benefits over environmental ones (Van der Byl & Slawinski, 2015). This type of approach follows the traditional managerial (or win-win) paradigm in which environmental aspects are only considered if they are able to create economic benefits.

According to the paradox view to corporate sustainability, understanding and embracing the tensions would be the first, necessary step for managing them (Hahn et al., 2015, 2014; Smith & Lewis, 2011; Van der Byl & Slawinski, 2015). This would not mean a categorical selection of one aspect of sustainability over another, but accepting the competing demands and inherent complexity related to sustainability, and learning to live and to balance between these demands. The paradox view would allow companies to emphasize environmental or social benefits over economic ones (Hahn, Figge, Pinkse, & Preuss, 2018), at least occasionally. While alternative strategies for managing these tensions have been proposed in the literature (Smith & Lewis, 2011), more empirical research is needed in order to understand how managers learn to identify, accept and manage these tensions in practice (Van der Byl & Slawinski, 2015).

In the context of sustainability assessment, handling trade-offs between environmental, economic and social aspects is one of the key questions. Trade-off thinking is at the core of life cycle thinking, which aims at making potential trade-offs between life cycle phases and environmental impacts measurable and visible. However, depending of the applied assessment method, the decision related to

handling these trade-offs is often left outside the scope of the study. This would require making a value choice related to superiority of the studied aspects in relation to each other. Although there are methods available that can be used for making such value choices, their use may feel contradictory because they are not in line with the traditional view of science. Reflecting the traditional epistemological differences between natural and social sciences, the role of values and value choices has long been debated in the context of the life cycle assessment (Finnveden, 1997; Freidberg, 2018; Hertwich, Hammitt, & Pease, 2000). The existing ISO standards for a life cycle assessment reflect the positivist view of science and consider the approaches that require value choices as non-scientific (Pizzol et al., 2017).

In addition, as the assessments are rarely able to include all relevant aspects of sustainability, another core challenge is related to including information and impacts that are difficult to quantify. Within management, measurable environmental targets are considered to promote action, whereas unmeasurable targets are unlikely to be prioritized (Nilsson-Lindén et al., 2018). Consequently, measurement and management might be focused on aspects that can be measured, instead of the ones that would require attention. Thus, from the sustainability assessment practitioner point of view, central paradoxes in sustainability assessment are related to balancing between measurable and non-measurable information, and combining fact-based and value-based information.

For the moment, most of our decision-making processes seem to be dependent on availability of measurable (and if possible, monetary) information. Management scholars have highlighted the need for "transparent and efficient metrics" (Dyllick & Muff, 2016, p. 170) and "explicit and systematic analysis of trade-offs in corporate sustainability" (Hahn et al., 2010, p. 219) as necessary means in a move towards more sustainable organizational practices. However, in the context of sustainability, providing measured information is not straightforward. A continuous challenge faced during the assessments is that determining the appropriate level of sustainability is often dependent on the context (Dijk et al., 2017; Kemp & Martens, 2007; Martens, 2006) and it may be difficult to say what is sustainable.

Despite the central role of performance measurements in sustainability management, it seems that paradoxes related to measurability of sustainability have not gained much attention within the literature that focuses on sustainability performance. Within the corporate sustainability literature, trade-offs related to what can be measured and what should be measured have been addressed by Delmas and Doctori Blass (2010) in the context of corporate responsibility ratings. Their findings highlight how a lack of publicly available environmental data might lead to including indicators that can be measured instead of indicators that should be measured (Delmas & Doctori Blass, 2010). They also point out the challenges in comparing the environmental performance of different companies. However, Boiral and Henri

(2017) state that idea of comparability of sustainability information is usually taken for granted, and not really questioned. They propose three alternative views for considering measurability and comparability of sustainability information:

- The functionalist view is prevailing in literature, and according to this view, sustainability can be comparatively measured using standardized frameworks and indicators. Challenges related to comparability can be addressed by providing more specific (quantitative) information.
- The critical approach considers that challenges in incomparability are due to companies and managers controlling the information, and unwillingness to be truly transparent or disclose negative information.
- The postmodern perspective considers that the reason for incomparability is the very nature of sustainability as a complex and non-measurable concept (Boiral & Henri, 2017).

In their call for the ecological case for business, Ergene et al. (2020) point out that among the core problems within the current ecological crisis is the managerial, human-centric epistemology, which considers nature as a resource and ecological crisis as an issue to be managed. From critical epistemology point of view, managing the natural environment can be seen as "a modernistic ambition that aims to control nature" (Ergene et al., 2020, p. 7). From this it would follow that most of the attempts to measure sustainability could be considered as part of the modernist attempts to manage nature, as most of the available quantitative methods are based on causal relationships that aim to simplify natural complexity as measurable components. From a critical perspective, considering or assessing sustainability at the organization or firm-level level is not adequate or appropriate, hence conflicting with the original idea of sustainability, especially if it is considered from the ecological point of view (Isil & Hernke, 2017).

Positivist, functionalist and managerial tendency may also be recognized in analytical sustainability assessment methods like LCA and multi-criteria decision-making, which have been applied within the case studies included in this thesis. These methods are commonly applied for purposes of sustainability assessment. Especially the different LCA-based methods are applied by companies for the purposes of product development and communication (Pihkola et al., 2017). In this study, it is considered that better understanding about the functioning of these assessment methods and tools, together with their limitations, should increase understanding about the complexities related to both managing and measuring sustainability and related trade-offs.

Previous studies have pointed out that there is a need for tools that could be systematically used for measuring and managing trade-offs related to sustainability (Hahn et al., 2010). In their review of the literature on trade-offs related to corporate

sustainability, Haffar and Searcy (2017) acknowledge the importance of trade-offs related to the measurement and management of sustainability. According to their classification, these trade-offs represent the micro-level of operation, which is related to how sustainability is implemented in practice and to what kind of measures are used for evaluating sustainability performance (Haffar & Searcy, 2017). However, their findings also highlight how the literature addressing the tensions related to measuring corporate sustainability is still relatively sparse (Haffar & Searcy, 2017). This study aims at addressing this gap and considers the ability of analytic sustainability assessment methods to help in identifying and understanding the different trade-offs and paradoxes related to sustainability.

3 Theoretical framework

This study belongs and contributes to the field of management and organization studies. It uses a transdisciplinary research approach and considers how sustainability assessment could contribute to the field of sustainability management. The specific focus of this study is on the use of life cycle-based assessment methods and life cycle thinking as part of sustainability assessment and management. Each of the abovementioned topics are broad and address questions that have many similarities, but they typically use different methods and theories and emphasize slightly different aspects.

Previously, the focus of sustainability management literature has been on the social and organizational aspects of sustainability (Starik & Kanashiro, 2013). In contrast, sustainability assessment literature has been more focused on the biophysical aspects of sustainability, and to the material and energy flows and related environmental impacts (Baumann, Lindahl, Scandelius, Schmidt, & Sonnemann, 2018). However, what is common to these fields of research is that they both try to address sustainability challenges, and apply a systems approach. The transdisciplinary nature of this study is based on an attempt to integrate knowledge from these closely related but still separated fields of study, and show how these fields could learn from each other and together make a stronger contribution in solving both local and global sustainability challenges.

An overview of the theoretical framework that applies sustainability management together with sustainability assessment is presented in Figure 1. In addition to sustainability management and sustainability assessment, the framework includes the life cycle thinking and life cycle management approaches, together with short introductions of life cycle assessment and multicriteria decision-making methods. Both methods have been applied in the case studies that are presented in Chapter 4.

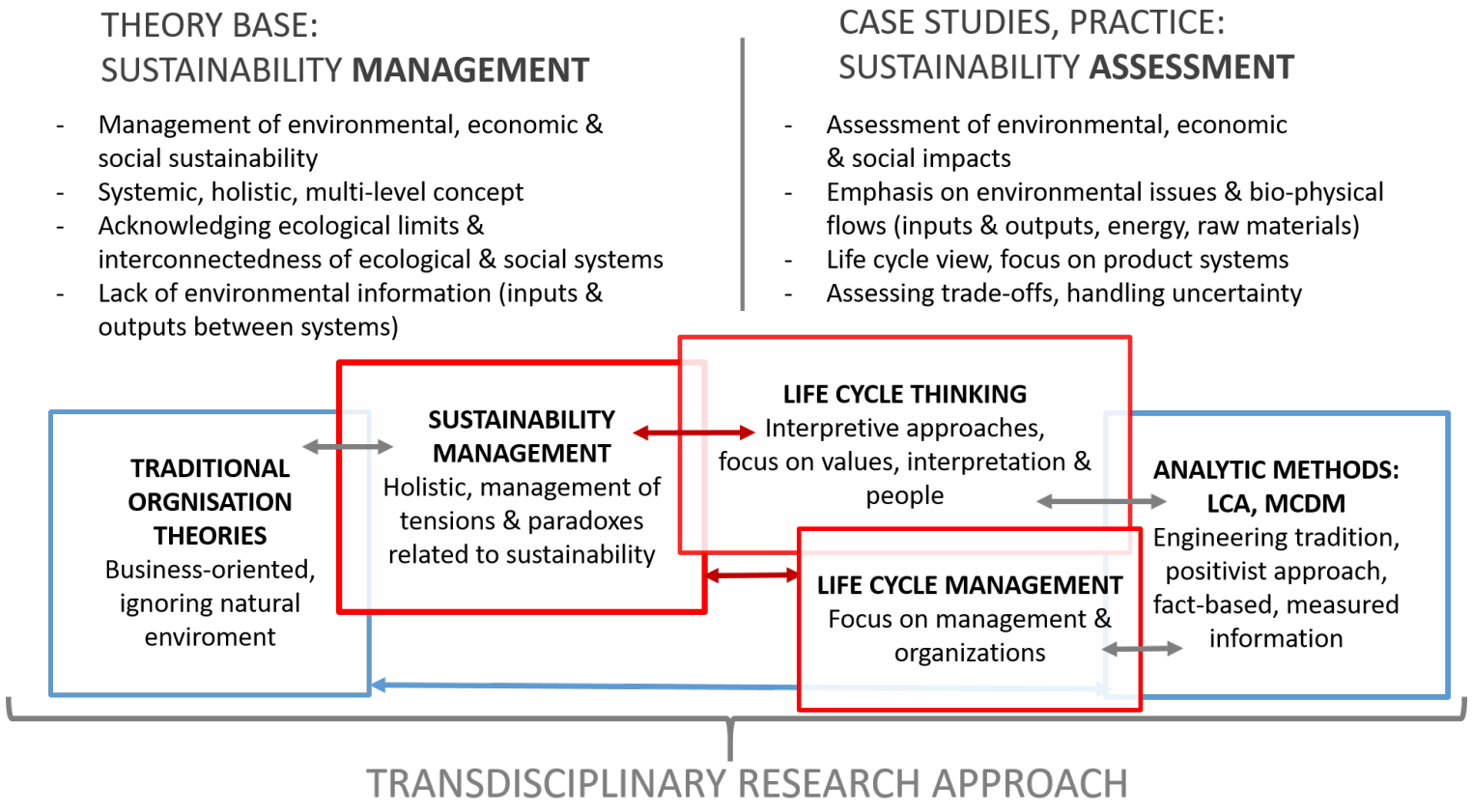

Figure 1. An overview of the theoretical framework applied in this thesis

3.1 Sustainability management

In this study, sustainability management is considered as a multilevel-systemic concept, according to the prototheory presented by Starik and Kanashiro (2013). Building on several earlier studies[2], they define sustainability management

> "as the formulation, implementation, and evaluation of both environmental and socioeconomic sustainability-related decisions and actions" (Starik and Kanashiro, 2013, p.12).

Sustainability management considers all environmental, economic and social aspects of sustainability, as those are often interconnected and cannot be totally separated. However, the main focus of this study is on environmental sustainability. According to Starik and Kanashiro (2013), the theory of sustainability management would need to focus significant attention on both natural and socioeconomic environments, and if possible, on building mutual feedback loops between the multiple environments. Thus, questions related to measuring and evaluating sustainability and collecting environmental information are central for sustainability management.

Sustainability management builds upon the discussions and theories related to organizations and the natural environment and environmental management (See e.g. Starik and Marcus, 2000; Williams et al., 2017), but also on those related to corporate sustainability (Montiel & Delgado-Ceballos, 2014). In his editorial for the *Organization & Environment* journal, Starik (2013) describes that compared to earlier research related to organizations and the natural environment, which was closely related to environmental sociology (focusing more on the societal-level actors and phenomena), sustainability management research is more focused on environmental and social aspects within and between organizations, on individual businesses, organizations and actors. On the other hand, Dyllick and Muff (2016) have criticized sustainability management studies for focusing too much on the organizational level. They propose that studies in sustainability management should focus on the role of companies in making the world a more sustainable place (Dyllick & Muff, 2016). Thus, more attention should be paid on the ability of companies to contribute to sustainable development as a societal goal. However, within a multi-level and systemic approach, both micro- and macro-level aspects should be considered.

[2] Starik & Kanashiro (2013) refer to studies conducted by Bell & Morse (2008), Dunphy, Benviste, Griffiths & Sutton (2000), Elkington (1998), Laszlo (2003) and Stead & Stead (2004).

According to Starik and Kanashiro (2013), the need for new theory that is dedicated to sustainability management is motivated by the inability of current, mainstream organizational and management theories to sufficiently focus on sustainability challenges. In addition, they call for more cross-disciplinarity in sustainability management research, stating that the disciplinary basis of the current management and organization theories is too narrow for addressing the complexity that is related to most sustainability issues (Starik & Kanashiro, 2013).

As discussed earlier in Chapters 1 and 2, similar calls for more transdisciplinary and cross-disciplinary research were made in the early days of organizations and environment debate. Nonetheless, recent reviews show that much more would need to be done, especially for integrating research related to the natural and socioeconomic environments (Linnenluecke & Griffiths, 2013; Whiteman et al., 2013), and highlighting the systems perspective that is considered necessary for addressing the interconnectedness of ecological, social and economic issues (Williams et al., 2017). Traditionally, management and organization studies have been more focused on the human, social and organizational aspects related to sustainability (such as the motivation for integrating sustainability), and on studying the relationship between sustainability and profitability (Montiel & Delgado-Ceballos, 2014). Less attention, however, has been paid to the actual environmental impacts related to business activities (Kallio & Nordberg, 2006).

Some authors have questioned the need for new, dedicated theories related to sustainability management, and argue that it would be more useful to further develop existing theories (such as the stakeholder theory), as those are compatible with the mainstream business models and theories that are commonly applied and understood in the business world (Hörisch, Freeman, & Schaltegger, 2014). Hörisch et al. (2014) underline the importance of speaking the same language, rather than developing a new one. However, as discussed in Chapters 1 and 2, the so-called managerial paradigm for corporate sustainability has been criticized for focusing too much on how sustainability aspects could be integrated within existing business models and practices. As a consequence, sustainability goals have often been reconciled to economic goals. Increasing popularity of business sustainability has not led to decreasing environmental burdens nor solving the many challenges related to social sustainability (Dyllick & Muff, 2016; Ergene et al., 2020; Margolis & Walsh, 2003).

According to the transdisciplinary research approach, it should be possible to do both: build a new theory that would be better equipped for managing the transformative change that would be required in organizations and in society, and further develop the existing, traditional theories that are already widely applied. Thus, in order to address the paradoxes related to sustainability, different kinds of development strategies should be applied together. Proponents of the so called

integrative view to corporate sustainability highlight how understanding tensions and paradoxes related to sustainability would be the first step for actually managing them (Hahn et al., 2010, 2015). Consequently, a critical issue for sustainability management would be to consider how increased understanding of environmental impacts could be transferred to actions that would actually reduce those impacts. Or more radically, how this understanding could be used for actually changing the way business is conducted.

Hahn and colleagues (2014) apply the idea of cognitive frameworks that could be used for managing the tensions and paradoxes inherent in all decision-making related to sustainability. Building on the works of Smith and Lewis (2011), and Smith and Tushman (2005) that developed the theory of paradox, they discuss two, ideal types of cognitive frames: a business case frame and a paradoxical frame. The existence of the two frames could be used to explain how managers deal with ambiguities related to sustainability. Managers applying the so-called business case frame are trying to minimize conflicts and align other sustainability aspects with the financial performance of the company (Hahn et al., 2014), whereas managers applying the so-called paradoxical frame accept the tensions and conflicts between environmental, economic and social aspects, and recognize complexity as an essential element of sustainability. In practice, decision-makers most likely apply elements from both frames, and these ideal types as such do not exist in their simplest form (Hahn et al., 2014).

According to their propositions, cognitive frames affect all phases of managerial sense-making, namely scanning, interpretation and responding (Hahn et al., 2014). From sustainability assessment point of view, and from the point of view of this study, the scanning phase seems especially relevant to consider. In the scanning phase, decision-makers aim to reduce the amount of information and notice different aspects that are considered relevant for the following phases of the decision-making process (Hahn et al., 2014). Cognitive frames might affect what kind of information is searched for and gets noticed and processed for further action. Hahn et al. (2014) propose, that managers with the business-case-oriented frame might be more likely to notice a narrow range of sustainability aspects, and conduct a focused search of information, with emphasis on quantitative information that could be linked with information about economic performance. Whereas managers with a more paradoxically oriented frame might be more likely to conduct wider searches and notice more aspects that can also be controversial (ibid). They can apply both quantitative and qualitative data, and digest related uncertainty. However, this wide search does not allow going into details in any of the studied aspects, which might cause difficulties in the following phases of the sense-making process (Hahn et al., 2014).

Building upon these propositions, Hahn and colleagues (2014) conclude, how managers with the business case frame and the paradoxical frame could play different kinds of roles in organizational change processes. According to their propositions, managers with a business case frame might be unwilling to do radical changes to existing practices, but their practice-oriented stance in reducing complexity and finding workable solutions might be necessary for promoting the change processes in organizations (Hahn et al., 2014). On the other hand, managers with a more paradoxical frame might be able to propose more creative or radical solutions, but due to their high awareness of related risks and complexities, they might be less capable of turning these ideas to implementable solutions (ibid). Since cognitive frames can develop over time, it is interesting to consider whether sustainability assessment methods could be capable of providing sustainability information in a way that would promote decision-makers with different cognitive frames to initiate change in their organizations.

3.2 Sustainability assessment

Sustainability assessment is an interdisciplinary and practice-oriented field of research that is divided into many different subfields and areas of specialization. Different methods and approaches for the assessment are applied in different contexts that range from product- and company-specific evaluations to policies and regional assessments (see e.g. Ness et al., 2007). Sustainability assessment (SA) methods are required for assessing the impacts of production and consumption, for evaluating the current state and potential progress achieved (Ness et al. 2007). In addition, sustainability assessment should be applied for identifying solutions that are able to promote transition to sustainability (Dijk et al., 2017; Pope, Bond, Hugé, & Morrison-Saunders, 2017; Sala et al., 2015).

A common definition for sustainability assessment is currently lacking (Dijk et al., 2017; Pope et al., 2017). In its broadest sense, sustainability assessment has been defined as “any process that directs decision-making towards sustainability” (Hacking & Guthrie, 2008). Sustainability assessment methods can be categorized (for example) according to their decision-making context (such as product, project or policy), their temporal focus (prospective or retrospective, ex-ante or ex-post assessment, their integratedness (how many aspects of sustainability are included) and their strategicness (Hacking & Guthrie, 2008; Ness et al., 2007; Sala et al., 2015; Sala, Farioli, & Zamagni, 2013). Integratedness usually refers to the ability of the methods to handle and integrate different aspects of sustainability. This may mean, for example, different environmental aspects, or a combination of environmental, economic and social assessments.

In addition, different assessment methods typically focus on different questions and different levels of assessment, and might come up with very different solutions (See Dijk et al., 2017). This is often difficult to understand for persons who are not experts within the assessments. Therefore, it is important to discuss the purposes and values behind selecting specific assessment methods and tools, and understand how the choices made before and during the assessments affect the results and their interpretation (Dijk et al., 2017; Freidberg, 2018; Morrison-Saunders & Pope, 2013). These choices usually have an impact on the results of the assessment. However, the choices might be considered as merely technical issues that need to be solved, rather than value choices, unless made explicit during the assessment process.

Another potential way to characterize available assessment methods relates to their level of stakeholder involvement. Using classification presented by Van Asselt (2000), Dijk et al. (2017) describe methods as either participatory or analytical. Participatory methods emphasize stakeholder views (subjective knowledge elements), while analytical methods usually focus on models, scenarios and data, and providing measurable information (objectified knowledge elements, or 'scientific facts' (Dijk et al., 2017, based on Van Asselt 2000). Another common classification refers to the positivist and interpretive nature of the different assessment approaches. According to positivist approaches, it is possible to gain knowledge about existing entities by simply measuring them, whereas the interpretive approaches emphasize that everything that happens is mediated by interpretive schemes and social actions (Dijk et al., 2017).

Recent studies have highlighted the need to combine both participatory and analytical elements in sustainability assessments (Dijk et al., 2017; Moeller et al., 2014; Sala et al., 2015). This would be necessary for integrating findings from both natural and social sciences, and including human aspects and values that are necessary to consider, but very difficult to include in a model (Moeller et al., 2014). However, the positivist and interpretive approaches have long lived separated from each other, and combining them in practice is not easy (Dijk et al., 2017). Within the field of management and organization studies, Ergene et al. (2020) have highlighted how the ontological and epistemological differences between natural and social sciences may lead to differences in both studied research questions and applied research methods.

Some of the methods that are now applied for sustainability assessment have been originally developed for other purposes, such as the generic decision-support tools like multicriteria analysis or cost-benefit analysis (Ness et al., 2007). Many of the methods have been originally developed for the purposes of environmental assessment, and they have been later extended to include other sustainability aspects. Several frameworks for sustainability assessments have been proposed in the

literature (See e.g. Sala, Ciuffo and Nijkamp, 2015; Pope et al., 2017), but there is no single and commonly applied procedure that could be used for sustainability assessment, and thus the procedure is often dependent on the researchers conducting the assessment (Dijk et al., 2017; Pope et al., 2017).[3]

Thus, it could be said that sustainability assessment is a heterogeneous field, which is divided into several subfields or assessment traditions, depending on the applied methods and contexts of the assessments. Different assessment methods and approaches also differ in whether they relate more to the interpretive or positivist tradition. One of the subfields has been focused on evaluating the impacts of products, using mostly analytical methods like life cycle assessment. Another tradition is based on the use of ex-ante impact assessment methods that are applied for evaluating the impacts of policies, plans and projects (Pope et al., 2017). In principle, similar phases are possible in all different assessment contexts, but the actual case defines how the phases are realized in practice (Sala et al., 2015).

Recent works by Sala et al. (2015, 2013) and Dijk et al. (2017) aim to holistically consider the field of sustainability assessment, taking into account different methods and decision contexts. In practice, researchers or consultants have often been specialized in using specific methods or focused on certain types of assessments, such as policy, product or regional assessments. As with any other research topic, one method is usually capable of addressing specific questions related to the studied problem. Methods that have been developed for micro-level assessments usually are not able to address macro-level questions, and the other way around.

Sustainability assessment has been criticized for focusing too much on assessing and improving the current situation, rather than aiming towards transformative changes within business or society (Sala et al., 2015). As discussed earlier, similar critique has been presented towards sustainability management (Dyllick & Muff, 2016). While it is easy to agree to this criticism, from the point of view of a sustainability assessment practitioner, it can be contested by saying that the problem is not about the lack of methods or indicators, but rather on how we use them, and how we deal with the information these methods are able to create. Thus, in addition to actual evaluation methods, it would be necessary to consider the managerial, social and organizational aspects related to sustainability assessment, how it is conducted, and how the information could be utilized to support decision-making.

[3] Exceptions are the Environmental Impact assessment (EIA) and Strategic Environmental Assessment methods, which are used for evaluating the impacts of large projects, policies and programmes. The procedures for these assessments are described in European directives and national laws. EIA is required before realization of large projects like power plants and highways. SIA is required in the planning phase of large projects and programmes that are expected to have significant impacts on the environment. Examples include land use policies and nature conservation programmes.

This study is focused on benefits and challenges related to using product-based assessment methods in sustainability assessment projects. A special focus of the study is on the use of life cycle assessment and life cycle thinking, which have been applied in the case studies. In addition to LCA and life cycle thinking, a generic decision support method, multicriteria decision-making was applied in one of the case studies. The main principles of the applied methods are presented in the following Chapters 3.2.1 and 3.2.2.

3.2.1 Life cycle assessment

Life cycle assessment is a systematic, quantitative environmental assessment method that has been developed for evaluating the environmental impacts of products. In LCA, the life cycle of a product is modelled starting from raw material acquisition through manufacturing, use and recycling, re-use or disposal. In addition to products, LCA maybe applied for evaluating the impacts of technologies, services and organizations. The four main phases of LCA include i) goal and scope definition, ii) life cycle inventory, iii) life cycle impact assessment and iv) interpretation of the results (ISO 14040, 2006).

Within the inventory phase, all inputs (raw materials, energy) and outputs (products, by-products, waste, emissions) that take place during the life cycle are included within the product system. Within the life cycle impact assessment (LCIA) phase, the significance of the potential environmental impacts is evaluated, based on the inventory results. Within the inventory phase, relevant impact categories, category indicators and characterization models are selected. The inventory data that include information about different emissions are first classified and then characterized into the selected environmental impact categories that may include many different impacts such as climate change, acidification, eutrophication, photochemical oxidant formation and resource depletion. Optional steps after characterization include normalization, grouping and weighing (ISO 14040, 2006).

Life cycle assessment is a comprehensive environmental assessment method that should include several environmental impacts, but the coverage of different environmental impacts varies between studies. In principle, the goal of the assessment is to include all potential environmental impacts of a product life cycle, but this is rarely possible in practice.

An LCA study includes collecting and handling large amounts of process data and environmental impact information, and specific LCA software tools are applied in the process. Some data is usually collected from the product system, and generic data from public and commercial LCA databases can be used to complement the assessment. Databases are often necessary, since it is difficult to acquire detailed information about all processes taking place outside one’s own organizational boundaries.

The development of environmental life cycle assessment started already in the late 1960's (Guinée et al., 2011). The use of the method is guided by several international standards and guidelines. Important guidelines include the ISO standards related to LCA (ISO14040-44) the ILCD handbook published by the European Commission, and the documents published by the United Nations Life Cycle Initiative.

Among the commonly applied life cycle-based assessment methods are the carbon footprint (which is an LCA focused on greenhouse gas emissions and global warming potential only) and the water footprint (which is focused on emissions and impacts that relate to water availability, use and quality). During recent years, the use of LCA has increased, and the scope of life cycle-based methods has been extended from environmental impacts to other sustainability aspects, due to the development of the life cycle costing method, the social life cycle assessment method and the life cycle sustainability assessment framework (Guinée et al., 2011). Compared to the environmental life cycle assessment, the social and economic approaches, together with the comprehensive life cycle sustainability assessment framework, are still in the development phase (Petti, Serreli, & Di Cesare, 2018; Tokede & Traverso, 2020; Wulf, Zapp, Schreiber, Marx, & Schlör, 2017; Zamagni, Pesonen, & Swarr, 2013).

Currently, European environmental policy recommends the use of life cycle assessment for evaluating the environmental impacts of products (European Commission, 2003). Recent examples include the product environmental footprint (PEF) and organizational environmental footprint (OEF) guidelines prepared by the European Commission together with the manufacturers (European Commission, 2013). In addition, life cycle thinking is a central element within the European waste management and circular economy policies (European Commission, 2015).

Within the sustainability management literature, life cycle assessment has been mentioned as one of the advanced methods for environmental management, but despite few exceptions (see e.g. the work of Heiskanen, 2000, 2002; Lazarevic & Martin, 2018; Rex & Baumann, 2008), its use within management and organization studies has been quite rare. Within management literature, LCA studies may be considered as part of industrial ecology (Williams et al., 2017) or considered as technical studies that are separated from the organizational sustainability measurement literature (Mura et al., 2018).

In this study, LCA was applied in case studies II and IV. In case II, life cycle LCA was applied as one of several methods within a sustainability assessment. Case study IV focuses on questions that are relevant when LCA results are used for stakeholder communication purposes. Case I uses life cycle-based information, and applies the principles of life cycle thinking for evaluating the environmental impacts related to use of ICT and mobile networks.

3.2.2 Multicriteria decision-making

Methods for multicriteria decision-making (MCDM)[4] were originally developed as generic decision support tools, but they are increasingly used in the context of environmental assessments and sustainability assessments (see e.g. Kiker et al., 2005; Ness et al., 2007). One of the areas in which MCDM methods have been commonly applied is waste management (Goulart Coelho, Lange, & Coelho, 2017). MCDM can be used for identifying preferred alternatives in a situation where there are multiple alternatives to choose from and several objectives that should be met. It is a structured, quantitative method that can be used for analysing complex decision-making situations. Thus, MCDM is an analytical method, but if it is used for group decision-making purposes or stakeholder consultation, it includes also participatory elements.

Group-based MCDM can be used for gathering stakeholder views, and for highlighting both similarities and differences between the views of different participants. MCDM can be used for building consensus, but also for highlighting potential sources of conflicts (Kiker et al., 2005). Kangas et al. (2001) present examples of processes in which MCDM methods have been used for planning acceptable forest management options while integrating the views of different stakeholders. The aim of MCDM methods is to help people in analysing multiple streams of dissimilar information in a systematic way (Kiker et al., 2005). This is a typical situation in a sustainability assessment, where several information sources have been used.

In the context of a sustainability assessment, trade-offs between different sustainability aspects are often revealed, and the values of participating stakeholders are discussed during the process. In addition to values, participating actors or stakeholders may have many conflicting interests and opinions. In addition to stakeholder involvement, MCDM methods can be used for complementing other methods, such as life cycle assessment (Seppälä, Basson, & Norris, 2002). In these cases MCDM could be used for weighing the studied environmental impacts in relation to each other and considering for example, whether more weight should be given for options that reduce global warming potential or for those that reduce marine eutrophication.

Several different MCDM methods exist. Central phases in a MCDM process include goal and scope definition, criteria and indicator selection, data normalization, weighing attribution and sensitivity analysis (Goulart Coelho et al., 2017). The decision problem is often described as a matrix which describes the alternatives

[4] Alternative terms used in the literature include, for example, multicriteria decision analysis, multiple attribute decision analysis and multicriteria analysis.

according to their performance in the selected criteria (Goulart Coelho et al., 2017; Kiker et al., 2005). In principle, participatory elements may be used in all phases of the assessment.

In this thesis, two value-based optimization methods, namely Analytic hierarchy process (AHP) and Multi-attribute value theory (MAVT) were applied in the context of a circular economy-related research project (see case study III). The aim of the MCDM was to prioritize the bottlenecks that should be removed in order to increase recycling of end-of-life vehicles and plastic packaging waste. MCDM methods may bring many benefits in structuring and thoroughly analysing the decision-making situation and available alternatives. However, the process also includes many choices that affect the outcome of the assessment. These are discussed as part of case study III. Like sustainability assessment, the results of a group based MCDM are very much context related, and thus the generalization of the results may be challenging.

3.3 Life cycle management and life cycle thinking

Industrial ecology and life cycle management are research fields that are specialized in analysing material and energy flows between different organizations and throughout product life cycles, with the overall aim of finding synergies and reducing environmental impacts. However, both fields have been mostly focused on the technical aspects related to managing and measuring the physical flows, and have given less consideration to the social or managerial aspects related to these (Baumann et al., 2018; Hoffman, 2003; Korhonen et al., 2004; Nilsson-Lindén et al., 2018).

Several potential concepts and definitions for life cycle management (LCM) have been proposed (Poikkimäki, 2006), and many normative propositions on what it should contain have been made in the literature (Nilsson-Lindén et al., 2018). However, Nilsson-Linden et al. (2019) point out that less guidelines for practical implementation have been proposed. According to Linnanen and colleagues (1995), life cycle management consists of three views that relate to management, engineering and leadership:

- the management view consists of integrating environmental issues into company decision-making,
- the engineering view relates to optimizing the environmental impacts caused by products during their life cycle, and
- the leadership view which consists of creating a new organizational culture.

When considering the definition presented by Linnanen et al. (1995), this study is interested especially in combining the aspects that are relevant from management and engineering point of views. Based on an analysis of several LCM definitions, Nilsson-Lindén et al. (2018) state that the common aspects in different LCM definitions include "a holistic approach to environmental issues along the product chain and a striving to reduce environmental load throughout the product life cycle, both of which require that organizations look beyond their organizational boundaries".[5] As such, the life cycle management definition seems compatible with the systems theory approach that is at the core of sustainability management theory, as formulated by Starik and Kanashiro (2013).

Life cycle thinking (LCT) is another related research approach that highlights the importance of a life cycle view in the context of environmental issues. The life cycle thinking approach is interested in human and organizational factors that affect how life cycle assessment and other methods and tools are organized and applied in organizations (Nilsson-Lindén et al., 2018). However, compared to studies related to technical aspects of LCA and life cycle management, studies focusing on life cycle thinking are more rare. Rex and Baumann (2008) highlight, how majority of studies related to LCA practices in organizations have followed a functionalist approach that focuses on the importance of structural characteristics (such as industry sector and firm size), instead of considering the potential influence of individual actions and preferences. Similarly, they point out, how the functionalist paradigm has been dominant also within the field of organization studies (Rex & Baumann, 2008).

Fullana i Palmer et al. (2011) argue that over the years, much effort has been put into developing LCA as a scientific method, and in providing *"the right answers"* to policy makers and other decision-makers. However, in future more emphasis should rather be put on how LCA could be used for identifying *"the right questions"* (Fullana i Palmer et al., 2011). This would be the role of life cycle thinking, which would require cooperation with social scientists and economists (ibid). Rex and Bauman (2008) state how the traditional view in dealing with LCA-related challenges has emphasized the development of better methods and tools. According to this view, challenges related to measuring and managing environmental impacts could be best dealt with by developing more efficient methods and tools that would be easier to apply. Interestingly, very similar proposals have been presented by the many sustainability management and corporate responsibility scholars, who have regularly pointed out the need to develop new, more efficient and standardized

[5] In their review, Nilsson-Lindén et al. (2018) refer to the definitions presented by Linnanen et al. 1995); Heiskanen (2002); Hunkeler et al. (2003); Remmen et al. (2007) and Power (2009).

metrics for sustainability measurement purposes (See e.g. Dyllick & Muff, 2016; Montiel & Delgado-Ceballos, 2014; Shrivastava, 1994, 1995a).

According to Nilsson-Lindén et al. (2018), life cycle thinking seeks explanations from human and organizational factors, rather than from specific tools or structural aspects. According to their findings, personal convictions and experiences affect the outcomes of any life cycle management activities (Nilsson-Lindén et al., 2018). Previous studies have shown, how individual actions and sense-making affect how the LCA work in organizations is shaped, leading to very different outcomes in structurally similar conditions (Rex & Baumann, 2007, 2008). Heiskanen (2000) proposed, how experiences and results from an LCA might lead to very different interpretations that might either promote or hinder environmental consciousness of individual managers. She proposes that in addition to the position of the company within the value chain and the organizational culture, individual interpretations affect how managers respond to life cycle based environmental information (Heiskanen, 2000). These findings are interesting also from the point of view of the cognitive framing approach proposed by Hahn et al. (2014) (discussed in the context of sustainability management in chapter 3.1). Together, these findings propose that the existence of potential individual differences in managerial sense making would be relevant to consider when the results of a sustainability assessment study are presented.

In this study, the life cycle thinking approach is seen, according to the definition provided by UNEP (2012), as a way of holistically thinking about sustainability impacts, and considering how, and what kind of information should and could be used for understanding sustainability challenges, and for making better decisions. Thus, it is considered that LCT highlights sustainability knowledge, related values and ways of thinking, whereas LCM is more interested in the practical management aspects related to sustainability. Principles of life cycle thinking were applied in all four case studies that are included in this thesis.

4 Results from the case studies

4.1 Introduction to the cases

This chapter includes the summaries of the case studies that form the empirical part of this thesis. The case studies show how sustainability assessment, LCA and MCDM are used in practice for evaluating and measuring sustainability. Additionally, they highlight some of the challenges that are related to the assessment process, and to the use of produced sustainability information.

Case study I is a literature study that was published in the cross-disciplinary journal *Sustainability*. Case II is a conference paper that was presented at the 13th International Greenhouse Gas Control Technologies Conference in 2016 and published as part of the conference proceedings in *Energy Procedia*. Case study III was published in *Detritus Journal*, which is a multidisciplinary journal related to waste resources and residues. Case IV was published in *the International Journal of Life Cycle Assessment*. The four studies are independent and they all address different situations and contexts in which sustainability impacts have been measured and communicated. Original research problems have been defined together with industrial experts and other stakeholders who were involved within the research projects.

Common aspects in the case studies include the use of analytic, quantitative research methods as part of the assessment together with qualitative methods and data (studies II, III and IV), and active stakeholder engagement (studies III and IV). All case studies apply the principles of life cycle thinking, considering how the information created from the assessment could and should be communicated (study IV) and used in order to minimize evaluated impacts (studies I,II,IV) or to prioritize future activities (studies II,III). Additionally, all studies apply a life cycle view, and the assessments cover the life cycle of studied products or technologies.

The background and starting point of all the case studies is in the physical world (energy and material flows and related environmental impacts, applied technologies and products). However, the communication of the results and consideration of the applicability of the information relate the studies to the social world (companies, consumers, legislation, and policy). In addition, the results from the studies highlight how sustainability impacts are related with the local infrastructure (such as the

energy system) and applied technologies and materials, but also with human behaviour. Additionally, the studies aim to make visible how the various choices and assumptions made during the assessments affect the results.

Each case study presents its own, context-specific and practice-oriented results in detail, but this summary focuses on the more generalizable outcomes that represent the scientific outcomes relevant for this thesis. In addition, the summaries briefly introduce the background for conducting the studies. Each study points out specific challenges that are faced during the assessment process, either related to conducting the assessment or communicating its results or both. According to Krohn (2008, p. 374):

> "transdisciplinary research projects combine ideographic concerns about problem solutions with nomothetic expectations of generalised knowledge. They may put more weight on one side or the other, but both orientations are present".

Thus, the case studies in transdisciplinary research have a dual nature: they should provide learnings that respond to the concrete real-life problems and are valid in that specific context, but they should also aim at producing transferable, generalized knowledge that could be applied in other contexts after validation and adaptation (Wiesmann et al., 2008). Needs related to generality can be reached by providing insights, models or approaches that could be applied in other contexts (Wiesmann et al., 2008).

Table 2 summarizes the applied methods, the contexts of the assessments and evaluated sustainability aspects in each case study. Chapters 4.2–4.5 present the main findings from each case study. Chapter 4.6 presents joint conclusions from all the case studies. Chapter 4.7 considers the ability of the applied sustainability assessment methods and case studies to reveal trade-offs within and between different sustainability dimensions, based on findings of the case studies. Identified trade-offs are analysed and summarized using an analytic framework proposed by Hahn et al. (2010).

Table 2. Summary of the applied methods, contexts and studied aspects

Study	Applied methods	Context of the study	Studied aspects
I	Literature review, energy intensity trend estimate	Evaluating energy consumption trends related to increasing use of mobile data in Finland, assessing its significance, and considering potential means for reducing future impacts	Energy consumption related to mobile networks, impacts of technology & consumer behaviour, studying impacts that take place at different levels, use of measured vs. non-measured data
II	Sustainability assessment (integrating findings from different studies & methods)	Sustainability assessment of carbon capture and storage (CCS) technologies, conducted as part of a project that developed solutions and considered applicability of CCS in Finland. Sustainability assessment was used for identifying potential drivers and barriers for implementing CCS.	Sustainability (political, economic, social, technological, environmental and legal aspects) of CCS technology, potential drivers & barriers for implementation, qualitative integration of information from different sources.
III	Multicriteria decision-making (group decision-making), literature review	Evaluating the importance of bottlenecks that hinder efficient recycling of cars and plastic packaging waste in Europe. Testing the applicability of MCDM methods for involving stakeholders and managing complex problems related to the circular economy.	Environmental, economic, social, legal and political aspects relevant to circular economy. Stakeholder involvement in the assessment process. Prioritising and making value choices based on various kinds of data using a quantitative method.
IV	LCA, workshops with group discussions & interviews	Studying the life cycle environmental impacts related to print products. Understanding impacts and informing stakeholders.	Environmental impacts of products, stakeholder needs related to sustainability communication, defining benchmarks for sustainability communication

4.2 Case study I: Evaluating the energy consumption of mobile data transfer

Study I considers the impacts of technological development and changing user behaviour in the context of information and communication technologies (ICT) and electronic services. The aim of the study is to evaluate the significance of environmental impacts related to the increasing use of mobile networks and data. Additionally, the study aims to argue why such issues would be important to consider in future studies, and why they should be communicated towards consumers.

In Finland, use of mobile data per person is the highest in the world. Amount of transmitted mobile data has increased rapidly, and continuous growth in data consumption is foreseen. At the same time, information related to energy consumption and other environmental impacts related to ICT and mobile services is fragmented, and understanding of total impacts is lacking. Within both scientific and professional literature, estimates about both increases and decreases in future energy consumption have been proposed, but there is lack of measured information that could be used for building more specific assessments. Thus, the aim of the study was also to understand whether the increasing use of mobile data could lead to an increase in overall energy consumption related to ICT or mobile services in Finland. While energy consumption is not an environmental indicator as such, it is often used to describe environmental performance, since energy production is usually a major source of environmental impacts. In addition, energy consumption is a significant cost factor.

Within the study, an electricity consumption trend-estimate for mobile data transfer (kWh/gigabyte) in Finland was built based on publicly available information, using basic statistical analysis methods. The created energy intensity estimate was compared with information available in the scientific literature. Additionally, potential future development trends related to both network technology development and consumer behaviour were discussed. The purpose of the discussion was to consider what would be the most effective means for reducing energy consumption and environmental impacts related to the use of electronic services and ICT. The analysis of the energy consumption trend-estimate and radio network technology development was complemented with a traditional literature review in which available studies addressing life cycle environmental impacts related to ICT and mobile networks were evaluated. The aim of the literature review was to understand the potential magnitude of the impact of mobile networks within the whole life cycle of mobile services. In addition to scientific articles, the review included information from technical reports, standards and policy documents.

The results from the study show that evaluating the environmental impacts of a fast-developing new technology is challenging, since both the evaluated technology and its use change rapidly. Required data is often missing, as statistics and other

publicly available data are published with delays. Available data is aggregated and it is difficult to allocate it to specific services or users. Detailed company- or location-specific data related to energy consumption is usually confidential. Existing data may consist of rough estimates which increases the uncertainty related to the evaluation. In this study, the overall energy consumption of mobile networks was estimated based on total energy consumption data that was published by the three largest Finnish mobile operators as part of their sustainability reports. While all reports applied the same GRI guidelines and reported the same indicators related to energy consumption, it was not clear if reported figures were defined similarly. However, sometimes even such uncertain data may be important for evaluating the significance of an impact, and to see where and by whom future actions would need to be taken. In this case, the constructed trend-estimate seemed to be in line with other figures and estimates that were found from the literature.

The results highlight that it is important to look at any sustainability aspect from different viewpoints and using different system boundaries, even if specific quantitative or measured data would be missing. In this case, the results show that the specific energy consumption per transferred gigabyte has decreased significantly between assessed years (2010–2017). Total energy demand of mobile networks has remained on the same level despite sharp increase in mobile data consumption (which can be considered as a positive achievement). However, due to continuously increasing consumption, the total energy consumption related to mobile networks may increase in the future. Thus, a rebound effect is taking place. A rebound effect is used to describe a situation in which increased production efficiency leads to increased production, and a consequent increase in total impacts, instead of savings.

However, it is quite difficult to evaluate the significance of this rebound effect, as it represents only one part of a larger entity. As described in the study, in 2017 the estimated total energy consumption of mobile operators in Finland represented 0.7% of the total annual electricity consumption in Finland. As a consequence, it could be stated that the amount of energy consumed for transferring the mobile data consumed by one inhabitant per year was not very significant, especially if it is considered in relation to all other consumption. In addition, ICT and mobile services are necessary for many functions of the society. In addition to negative impacts, mobile services create many benefits. Some of the services might substitute other services that could have consumed more energy. These substitution effects were not considered in this study.

From life cycle point of view, network energy consumption represents only one part of the chain. In previous studies, user devices have been the largest source of environmental impacts, due to their use phase energy consumption. The way consumers use available mobile services, and the type of devices they use, largely

determines the life cycle environmental impacts related to these services. However, consumers are rarely aware of these impacts.

Compared with the current situation, old TVs and desktop computers consumed a rather high amount of energy. New, energy-efficient devices (such as tablets and smart phones) are reducing this impact, but increasing use of videos increases the energy consumption in mobile networks. While end-user devices are getting more energy efficient, we have more devices per consumer and per household, and device lifetime is getting shorter. This is a challenge especially from resource use point of view, since many challenges in recycling of small IT devices exist, leading to considerable losses of resources. On the basis of available literature, increasing usage of devices together with increasing number of devices might have already exceeded part of the achieved savings. However, preparing exact estimates of all related impacts is difficult, due to wide variety of existing devices and many different use patterns.

On the basis of the experiences gained in this study, focusing on relative impacts (such as the kWh/gigabyte applied in this study) is useful for analysing development trends and understanding the impact of technology development. They can help in understanding a phenomenon and considering its significance. A move towards more energy efficient networks and ICT devices can be considered as positive development. However, if these development trends are not put into wider context, they may hide the fact that total consumption might be increasing, even if relative consumption per one instance of use would be decreasing. On the other hand, simply looking at the total energy consumption figures without considering the increase in the amount of produced services would not be correct either. It is necessary to understand the many different aspects that affect energy consumption as a whole.

In order to reduce environmental impacts related to increasing use of ICT, many kinds of actions are needed. It is necessary to engage with technology users (consumers), as investments in network technology development are not enough to cut energy consumption in the whole life cycle. If we want to inform consumers about sustainable and less consuming user habits, we need much more data from the life cycle of the devices and use of networks. This would require actions from companies operating along the life cycle of electronic services, including content producers and manufacturers of both network and end-user devices, and network operators. Authorities and related environmental or business organizations should promote availability of environmental information, which would be necessary for evaluating related impacts and engaging all relevant actors. Several actors in the value chain would need to be active in order to initiate a change that would allow reducing the overall impacts related to increasing ICT use.

4.3 Case study II: Integrated sustainability assessment of carbon capture and storage

Study II is a practice-oriented case study that describes the variety of aspects that need to be considered when evaluating sustainability of new technological solutions. The study presents the results from an integrated sustainability assessment that was conducted as part of a large national research project, in which the aim was to develop innovative solutions for capturing, storing and using carbon dioxide (CO_2) in Finland. Carbon capture and storage (CCS) technologies have been developed for reducing greenhouse gas (GHG) emissions originating from energy production and energy-intensive industries. Needs related to CCS for cutting GHG emissions have been highlighted in many climate scenarios and reports, even if the implementation of these technologies has not succeeded according to estimations.

In this case study, integrated sustainability assessment means that the study qualitatively integrates and summarizes the results from various assessments that covered analysis of selected economic, environmental and social aspects, potential risks for the environment, human health and safety and relevant aspects related to the legal and regulatory frameworks. Methods that were applied in the assessments included techno-economic assessment, environmental LCA, risk assessment (including analysis of the relevant environmental, health and safety requirements and Hazardous scenario analysis), stakeholder interviews, media analysis and literature reviews related to public acceptance and existing legal and regulatory frameworks.

Analyses of different sustainability aspects were conducted independently, but researchers were in contact with each other and exchanged information related to the progress and results from different studies. The need to combine the results from different analyses was recognized by participating researchers during the project, as it felt necessary to somehow integrate the large amount of information that was produced from different assessments. This was also considered useful from the point of view of the companies who participated in the project. As a consequence, the main findings from these independent assessments were integrated, summarized and communicated using the PESTEL framework (analysis of Political, Economic, Social, Technological, Environmental and Legal aspects). PESTEL was chosen since it allowed presenting together the many aspects that are relevant for sustainability and acceptability of a technology.

In this case, PESTEL was applied also for identifying aspects that could be considered as drivers or barriers either promoting or hindering implementation of CCS in Finland. Thus, the aim was not only to assess potential impacts, but to consider what should or could be done if CCS would be considered as an appropriate means for reducing GHG emissions in Finland. In addition, PESTEL was considered as a value-free framework, as it does not weigh different sustainability aspects against each other. However, here it is necessary to remember that within the

integration phase value-based expert judgement regarding potential significance of different results and their relation to each other had to be used.

The results from the study show how trade-offs may take place within and between different elements of sustainability, between geographic locations and different life cycle phases. CCS could be used for effectively and rapidly cutting greenhouse gas emissions in energy production, but it would mean accepting trade-offs between and within different elements of sustainability. From an economic point of view, this would mean accepting high costs. It was considered, that expensive investment and running costs related to the technology are major barriers for potential implementation of the technology. By the time of the study, also the price of the CO_2 emission allowances was very low (well below 10 euros/ton), which did not encourage expensive investments in technologies that would reduce those emissions.

From an environmental point of view, the conducted LCA studies revealed several potential trade-offs. The results showed how CCS could allow significantly reducing air emissions. In addition to CO_2 emissions, sulphur dioxide and nitrous oxide emissions originating from power plants would most likely decrease. Sulphur dioxide and nitrous oxide emissions contribute locally to acidification potential, whereas the CO_2 emissions contribute to global warming potential. However, at the same time, emissions originating from transports could increase, partly due to increased need for fuel, and partly due to the need to transport captured CO_2 to final storage site.

Implementing CCS to fossil power plants would mean continuing the use of limited fossil resources, which means that impacts related to sourcing of fuels would continue and possibly increase, as many CCS technologies increase the use of fuels due to low efficiency (so-called energy penalty). In the case of a coal-fired power plant, most life cycle emissions are created from the power plant when coal is burnt to create energy. Most of these emissions could be captured with CCS. However, environmental and social impacts related to coal mining are also significant and would continue, or even increase. These emissions would take place in another country (for example, Poland or China), depending of the assumed origin of the fuel. Thus, part of the impacts would be shifted from the energy production phase to both upstream and downstream in the life cycle, and to different geographic locations.

Due to the complicated nature of sustainability challenges, such as climate change, we need methods and approaches that are able to integrate and create a synthesis of studies that cover different sustainability aspects, and make them more understandable to different stakeholders. Similarly, it is important and useful for researchers from different fields to understand how their results relate to each other. However, results that are produced using different assessment methods and focusing on different sustainability aspects are usually not directly compatible nor

comparable. Presenting them together increases understanding of the studied phenomenon, but requires many simplifications. In addition, the level and source of uncertainty between different studies may differ, but this information is not easy to present in a compatible format.

The results from the study highlight on a general level the many trade-offs related to the concept of sustainability, since despite potentially significant GHG emission reductions, sustainability of CCS could be questioned from all three perspectives: environmental, economic and social. Often, technologies have impacts that can be both positive and negative. Whether the technologies or their impacts are considered sustainable or not, may depend of the context, and how the addressed problem is defined. Thus, the question is how much negative impacts are acceptable, if reducing greenhouse gas emissions would be considered as the most urgent and most important goal?

Consequently, providing simple recommendations related to most sustainable option might not be possible based on a sustainability assessment. Providing such recommendations would require a value-based judgement of the importance of different sustainability aspects against each other, and how they could or should be prioritized. This should include a clear definition of sustainability, against which other aspects could be assessed.

Finally, the results of the study show the interconnectedness of different aspects that are relevant when considering implementation of new technologies. For example, uncertainty related to future development of climate and energy policy was considered as a major barrier. In addition, available infrastructure may define what kind of options are possible in different time frames, and how much changes would be required to implement new technologies. While changes in existing legislation could be possible to achieve, they would require coordinated activities from the industry, authorities and politicians, whereas significant investments in infrastructures would most likely require financial support. While individual companies could perhaps act as promoters, cooperation and coordinated activities between actors would be needed. Most likely, this would require increasing stakeholder knowledge and further analysis of all relevant aspects from both sustainability and acceptability points of view.

4.4 Case study III: Advancing the circular economy through group decision-making and stakeholder involvement

While the circular economy is focused on improving resource efficiency, the concept has many similarities and interlinkages with the concept of sustainability, and one of the key principles is life cycle thinking. The circular economy is a political target

that should aim for creating economic growth and human well-being, and at the same time reducing the use of natural resources and operating within the limits of the Earth's planetary boundaries (European Commission, 2015). While it is not clear if this target can ever be achieved, it is closely related to many of the sustainability challenges our society is facing.

This study presents the results from a case study in which multicriteria decision-making methods were applied for evaluating the importance of bottlenecks that hinder efficient recycling of end-of-life vehicles and plastic packaging waste. Significant volumes of both waste streams are created in Europe annually. From environmental point of view, it would be important to reduce consumption of primary resources, and thus it is necessary to achieve significant improvements in recycling. However, as recycling also requires some resources, it is important to consider where additional research efforts, investments and regulations should be targeted at.

The novelty value of the study relates to applying the MCDM methods in the context of circular economy and using a value chain view in the study. MCDM methods can be used for structuring complex problems into more manageable components. When used for group decision-making, they can be used for both reaching consensus between participants and highlighting potentially conflicting interests.

While the study II presented an example in which results from different assessments were combined qualitatively, without clear value-judgements, the study III presents an example in which opinions from different actors are collected in order to prioritize alternative options, based on multiple criteria and using a quantitative approach. Applied value-based MCDM methods aim at producing an aggregated numerical score for each evaluated option on a cardinal scale. A central part of the assessment process is the weighing of the evaluation criteria. Each criterion is weighted considering its importance for reaching the goal that is defined at the beginning of the exercise. When conducted as a group exercise, an important part of the process is the discussion between participants, when each participant describes her own judgement, explaining the reasoning behind selected scores. The experts who participated in the workshop considered making trade-off comparisons of criteria performances as very difficult to perform. However, after getting familiar with the technique, they started to feel more comfortable in making those judgements and giving their answers. Reiterations were allowed, and discussions with others were encouraged throughout the exercise.

According to the MCDM methodology it is important to make sure that each participant understands the goal and the evaluated criteria in a similar way, so that the result would be representative of their joint interests. The experiences of the study highlight how it is possible to apply such methods in a group, and arrive to a

joint conclusion which satisfies the participants. However, the result has to be assessed in relation to the context in which it was produced, as the interaction between the participants shapes the results.

Even though MCDM methods have many benefits, their use is not without problems. In principle, the methods allow combining criteria that represent different sustainability aspects, but in practice the criteria might be narrowed down to the ones that can be measured. In the context of recycling value chains, many challenges were related to lack of appropriate data, which led to narrowing down the aspects that were included in the actual evaluation. In addition, integrating stakeholders (expert participants) in the process is time consuming, and the result is highly dependent on the availability and representativeness of the participating stakeholders. In this case, participating experts included representatives of recyclers, researchers, authorities, industry peer organizations and a customer industry representative (car manufacturer).

The results presented in the case study show that there are several bottlenecks that prevent efficient functioning of the recycling value chains. While some of the bottlenecks could be solved with new and more efficient technologies for sorting, separation and recycling, many of the bottlenecks are economic and regulatory in nature, or relate to consumer behaviour and product design. Thus, they are difficult to solve by the recyclers alone. In addition, different actors may have conflicting interests. As an example, some of the regulatory bottlenecks are related to ensuring product safety, but they may also prevent the use of recycled materials. In case there is no market demand for recycled materials, it is not reasonable for the recyclers to collect or process them, as increasing efficiency would increase costs related to recycling. At the same time, market interest towards recycled materials has been low (especially in the case of plastics), due to low price of primary raw materials, uncertainty related to quality and availability of recycled materials and strict legislation preventing their use. However, the European environmental policy calls for increasing levels of material recycling. Achieving the national and the European recycling targets requires significant improvements compared to current recycling levels. Therefore, cooperation along the whole product life cycle, and not only within the recycling value chain, is required for addressing these challenges.

The study concludes that group decision-making methods could be used as participatory methods that would allow collecting and integrating views of various stakeholders, and promoting knowledge exchange between the participants. This is important, since lack of cooperation and knowledge exchange has been identified as one of the barriers for moving towards circular economy solutions. However, use of structured analysis methods like MCDM is not without problems, and lack of appropriate, comparable data may jeopardize the comprehensiveness of the

assessment. In addition, making sure that the participants understand the applied method and its main principles is a significant part of the work.

Taking the views and opinions of the participants into account requires flexibility both in the applied methods and in the assessment process. In addition, it is important to analyse the result in relation to the context in which it was produced. The experiences gained from the study underline, that most important result might not be the quantitative ranking, but the discussion and learning that take place during the assessment, by all participants, including the researchers that facilitate the process.

4.5 Case study IV: Comparison of different normalized LCIA results and their feasibility in communication

Study IV is a case study that considers challenges related to sustainability communication. The study presents an example in which the normalization of LCIA results was conducted to make the LCIA results more understandable to those who are not experts in LCA. According to existing guidelines, environmental communication towards consumers should be clear and understandable, based on facts, and preferably cover the whole life cycle of a product. However, this can be difficult to achieve in practice. LCA results create a lot of detailed information that might be difficult to understand without a basic understanding of the method and the terminology used. In the case study, environmental LCA results of print products (newspapers and photobooks) were used for developing communication material (fact sheets) that could be used for communicating about the environmental impacts of these products to different value chain actors and their stakeholders. Need for such targeted, science-based information was identified prior to the study. Thus, the goal of the study was to develop material that would be useful in practice, for example in informing customer and educating personnel about relevant environmental impacts related to print products. Detailed results from the assessments were presented in separate project reports.

During the time of the study, carbon footprint was still a new concept and it was not exactly clear how it should be measured, or what would be the most significant life cycle phases or environmental impacts for print products. The printing industry had gone through many technological changes, and digital printing technologies were getting more popular. Measured data that would have allowed conducting environmental assessments (such as LCAs) for different print products was lacking. This study was part of a larger research project which first aimed at collecting relevant data covering the life cycle of print products. Second part of the project consisted of conducting several life cycle assessments for different print products.

Communication materials were developed together with industrial actors who were active participants in the process. Their input was collected using theme interviews in which challenges and needs related to sustainability communication were discussed on a general level. In addition to industry actors, representatives of important stakeholder groups were interviewed (such as researchers, customers & authorities). Additional group discussions were organized during a dedicated workshop. On the basis of the collected feedback, the content of the fact sheets was iterated.

In addition to needs related to communication, the case study discusses the use of normalization for making the LCA results more understandable to non-LCA experts. Normalization was selected, as it allowed describing the magnitude of the studied impacts in relation to other consumption. The goal of external normalization is to present case-specific LCIA results in a wider context. Need for a benchmark, or putting the results into a wider perspective was highlighted by the participating stakeholders. Direct comparison to other products from other studies was not possible, and normalization was selected as it was considered to be the best available option after careful evaluation of other existing measures for environmental communication.

In normalization, the environmental impacts created by the studied print products (such as a yearly subscription of a newspaper) were compared in relation to environmental impacts caused by an average European or Finnish inhabitant in 1 year. The reference values for Finnish consumption were used in materials targeted at Finnish stakeholders, whereas European values based on the ReCiPe method were applied for the materials targeted at European stakeholders. The normalized results presented the magnitude of each studied environmental impact in relation to the impacts of the selected reference system (environmental impacts caused by an average Finnish or European inhabitant per year). Thus, it is important to make sure that both the system boundaries and studied environmental impacts are as similar as possible within the original study and within the reference study. Within LCA standards (ISO14040-44), normalization is presented as an optional step of the assessment process because it is considered as bringing subjectivity to the results.

Overall, the results presented in the study show that one of the biggest challenges in sustainability communication relates to achieving a balance between simplicity and comprehensiveness of the provided information. Sustainability impacts and assessment results are context specific, and correct interpretation of the results requires that the context in which the result has been obtained is understood at least on a basic level. This includes basic understanding of the applied assessment method, and how it affects the results obtained. A considerable share of the developed fact sheets was dedicated in explaining the different assumptions and factors that affect

the results. However, all information should be kept on a generic level, so that it would stay understandable to persons who are not experts in the applied methods.

In addition, complexity is not only related to explaining applied methods or assumptions, but also to the studied environmental impacts. Thus, there is a need to explain the basic mechanisms related to climate change, acidification, eutrophication and other assessed impact categories. The more comprehensive the study (the more environmental or sustainability aspects are included), the more there is to explain. In the case study, materials focusing on only one environmental impact (climate change & carbon footprint) were considered the easiest to read and understand.

In addition, when results from several environmental impact categories (such as global warming, terrestrial acidification, fresh water eutrophication and fossil resources depletion) were presented together in the same fact sheet, a common question was related to the significance of those environmental impacts in relation to each other. Thus, many of the stakeholders were interested to know, which of the presented impacts was worst, or most significant? It was difficult to understand that such a comparison was not possible, as the different environmental impact categories were not comparable. This would have required separate weighing of the impacts and value judgments.[6]

In this study, normalization required using a vast amount of data on regional production and consumption (in Finland and EU), and this kind of data is not often available, which restricts the usability of such methods. In general, care needs to be taken in selecting the applied reference values, as they have an impact on the interpretation of the results and whether the impact of the studied product seems significant or not. Despite some complexity related to the method, the stakeholders who participated in the study considered it useful and important, as it allowed them to have an understanding of the magnitude of the studied impacts. However, equally important was to provide basic information about the studied emissions, and their contributions to different environmental impacts.

4.6 Conclusions from the case studies

The four case studies included in this thesis discuss some of the common challenges that are faced when measuring sustainability and communicating the results from the assessments. The study I discusses how energy consumption of mobile networks

[6] There are methods and approaches available in which expert opinions can be used for weighing the studied impact categories in relation to each other (see, e.g., Pizzol et al., 2017). Potential methods for weighing include the MCDM methods discussed as part of study III. However, the problem of these approaches usually relates to lack of transparency in underlying assumptions and criteria. Similar to normalization, weighing is considered an additional and optional step in ISO14040-44.

should be assessed in the wider context of ICT-related energy consumption and related consumer behaviour. In this context, both relative and absolute measures were considered useful and informative. Changing the perspective from direct energy consumption to indirect impacts and related behavioural changes is necessary for understanding the phenomenon and all related impacts. However, it makes the evaluation of those impacts very challenging. Life cycle view is necessary for understanding the phenomenon and for identifying relevant actors, yet quantifying and measuring all relevant impacts might not be possible. Nevertheless, it should be acknowledged that even without perfect knowledge it is already possible to start analysing and addressing the many aspects that constitute the bigger challenge.

The study II presents a research project in which the findings from many independent assessments were combined using a qualitative PESTEL framework. While the very idea of the studied CCS technologies can be considered as controversial, the study discusses challenges that are common to sustainability assessment of new technologies in general. In this case, the studied CCS technologies could be able to address one major problem (the urgent need to cut greenhouse gases from energy production), but there are many other impacts that should be considered too. Sometimes, the side effects might be too significant or controversial, but it is not easy to value them. Thus, the study II makes visible the kind of trade-offs that are often confronted in the context of a sustainability assessment. Currently, we do not have generally accepted measures for valuing those trade-offs. In this case study, making a value choice related to acceptability and sustainability of those trade-offs was left to potential users of the research results.

The study III presents an example in which two value-based methods of multicriteria decision-making were applied for prioritizing bottlenecks in two different recycling value chains. The MCDM methods are generic decision-support tools that can be used in the context of sustainability assessment, in order to conduct value judgements. Thus, in this case, making value judgements was a central part of the study. Experiences from the MCDM workshops highlight that systematic comparisons that are conducted during the process are useful for the participants for clarifying their own thoughts about the relations between evaluated options, and what is most important in each case. In addition, listening to arguments from other participants increases understanding towards their choices. However, when the final aggregated scores are formulated and presented, interpretation of the result becomes difficult for others.

The MCDM methods are often highlighted for their ability to produce quantitative, aggregated results that make different sustainability criteria compatible and comparable. However, in practice the discussed criteria and options might be narrowed down to the ones for which data is available, or which can be measured and integrated within available methods.

Study IV focused on challenges related to communicating results from a life cycle assessment study. The biggest challenge relates to making the results simple enough and understandable to persons that are not experts in the applied assessment methods. Understanding at least some of the uncertainties and complexities related to the assessment would be necessary for making reasonable judgements based on the results. This requires rather long and detailed explanations of the assumptions used in the study. However, many stakeholders would prefer to have simple guidelines for choosing the most sustainable option. Stakeholder attention is most easily directed towards those aspects that are easy to measure and communicate with benchmarks that the reader can understand.

Together, the results from the case studies show that measurements are usually far from being perfect or comprehensive enough, to catch all the aspects that would actually be relevant for assessing sustainability. However, even with imperfect methods and partial assessments, it is possible to increase knowledge and understanding of the studied issue. Not all produced information might be quantitative or compatible with economic information, but with some effort it can be presented side by side. However, digesting this often-fragmented and complicated information requires some effort from the respondents' side as well. Yet many of the stakeholders would prefer to have simplified results and clear answers that would tell what is sustainable and what is not. Even if the studied sustainability assessment methods can produce various kind of information, they can rarely answer this simple question directly.

In addition to the challenges related to measuring sustainability, the findings from the case studies I, II and III also highlight how managing the studied impacts would require coordinated activities between many different actors. Activities may be further hindered by conflicting goals, regulatory bottlenecks and economic constraints, as explained in study III. Consequently, it can be argued that challenges related to managing sustainability seem far greater compared with those related to measuring it. Because many of the challenges are difficult to handle by individual organizations, cooperation and knowledge exchange throughout the life cycle would be necessary.

4.7 Trade-offs identified in the case studies

In this study it has been argued that better understanding of potential trade-offs and complexities related to sustainability would be important for sustainability management. Consequently, one of the aims of this study was to critically consider the ability of the applied sustainability assessment methods to identify these trade-offs. This analysis is conducted by using a framework developed by Hahn et al. (2010) for analysing trade-offs related to corporate sustainability (see Table 3). The

framework was chosen as it provided a comprehensive overview of the many dimensions and levels of trade-offs that may be faced in the context of corporate sustainability and sustainability assessment in practice. On the basis of the findings from the case studies, some proposals regarding the development of the analytic framework were also made.

The original analytic model by Hahn et al. (2010) considers potential trade-offs at four different levels:

- Individual level refers to trade-offs faced by individual managers and decision-makers. These refer to situations in which individuals need to balance and to choose between environmental and economic values, or situations in which individual values conflict with organizational values.
- Organizational level addresses trade-offs that relate to impacts and outcomes of organizational activities.
- Industrial level addresses trade-offs that go beyond individual organizations, and relate to industries or sectors as a whole. These may also relate to cooperation between organizations and other actors, such as regulators or non-governmental organizations.
- Trade-offs at the societal level relate to the role of companies in contributing towards sustainable development as a societal goal. The societal level includes potential conflicts related to both intergenerational and intragenerational aspects of sustainability. Thus, it includes potential conflicts related to equitable use of resources and well-being between existing and future generations, and conflicts related to different interpretations of sustainability.

In addition, Hahn et al. (2010) propose that trade-offs may take place in three different dimensions that include an outcome, a process and a temporal dimension. Each dimension can be considered in each of the levels included within the framework. According to Hahn et al. (2010), the outcome dimension is central in sustainability performance measurement, as it considers the trade-offs in environmental, economic and social outcomes of the activities of an organization. The temporal dimension relates to trade-offs between short-term and long-term impacts and benefits, which are at the core of sustainable development. The process dimension refers to structural changes and larger transformations that should take place at the system level.

Table 3. Framework for analysing trade-offs, modified from Hahn et al. (2010).

	Outcome dimension	**Temporal dimension**	**Process dimension**	**Spatial dimension**
Societal level	Trade-offs between different economic, environmental and social outcomes at the societal level	Trade-offs between intra- and intergenerational aspects of sustainable development	Trade-offs between a more resilient and a more efficient economic system	Trade-offs between benefits and harms in different geographic locations
	Trade-offs between societal and industry levels			
Industry level	Trade-offs between different economic, environmental and social outcomes at the industry level	Trade-offs between present and future industry structures and activity with regard to sustainable development	Trade-offs within structural and technological change processes for sustainable development	
	Trade-offs between industry and organizational levels			
Organization, product or technology level	Trade-offs within and trade-offs between different economic, environmental and social organizational outcomes	Trade-offs between short-term and long-term sustainability orientation and effects of corporate activity	Trade-offs between different strategies and governance modes for corporate sustainability	Trade-offs related to different environmental, economic and social impacts in different locations
	Trade-offs between individual and organizational levels			
Individual level	Trade-offs between individual interests and preferences of different actors regarding economic, environmental and social outcomes	Trade-offs between short-term and long-term preferences and interests of different actors	Trade-offs between the perceptions of different actors regarding corporate sustainability	

In Table 3, the types of trade-offs that were addressed in this study are marked with green colour. The proposed additions to the framework are marked with a red colour. When considering the different dimensions presented in the framework, the findings from the case studies focus mostly on potential trade-offs that may take place within the outcome dimension (Studies I & II). In addition, potential trade-offs at the process dimension, within the industry level (Studies I, II & III) were addressed in this study. While the focus of (product- or technology-based) sustainability assessment studies is usually on the organizational or industrial level, multicriteria decision-making (which was applied within the study III) allows identifying potential trade-offs at the level of an individual or a group, depending on the goal and scope of the study.

While the framework highlights potential conflicts and trade-offs that take place between economic and environmental or economic and social aspects, practical trade-offs are also commonly faced within the different environmental aspects, as discussed in the studies II and IV. If several environmental impact categories are included within an assessment, it is rare to find solutions for which all impact category results would develop to a positive direction. As many methods are specialized in evaluating either economic, social or environmental impacts, they are most likely to discover trade-offs that take place within these dimensions. From sustainability point of view, and in order to avoid burden shifting, it is equally important to consider potential trade-offs within the different environmental (or social) aspects. Thus, it is proposed that the framework could be modified by highlighting trade-offs both *within* and *between* different environmental, economic and social outcomes, especially regarding the outcome dimension.

In order to reveal tensions between the different sustainability dimensions, it is usually necessary to use a combination of different methods and approaches, as was done in the case study II. Similarly, a combination of different methods and data sources would be required in order to study and to understand potential trade-offs that may take place between the different levels considered, as discussed in the study I. By using a combination of different assessment methods, it is also possible to extend the assessment and to identify potential trade-offs related to technological changes in the process level, as discussed in the case studies I and II, in the context of ICT energy consumption and CCS implementation. However, measuring these impacts in quantitative terms becomes challenging.

On the basis of the experiences and results gained from the case studies included in this thesis, the distinction between the different levels of the framework is not necessarily very clear in practice. When using life-cycle-based assessment methods, or life cycle thinking, the scope of the assessment exceeds organizational boundaries, but the studied impacts do not necessarily relate to the industry as a whole. Life cycle assessment may point out trade-offs especially at the organizational level and

sometimes also at the industry level, depending of the scope of the study. However, trade-offs faced at product or technology level are perhaps even more commonly faced in practice.

Environmental LCA is a micro-level assessment method, which is typically used for evaluating the environmental impacts of products, technologies or services. Addressing or evaluating potential trade-offs at societal level would require use of dedicated modelling tools or other macro-level assessment methods, such as the input–output analysis. However, the findings from the case studies propose that extending the quantitative assessments with more qualitative analysis allows analysing the interlinkages and trade-offs at the societal level too, as shown in the case studies I and II. For management purposes, it is important to understand the limits of applied assessment methods, as one assessment is typically able to produce information about limited number of aspects and levels at a time. In order to have a comprehensive picture, several assessment methods are typically required.

When considering practical needs related to sustainability assessment and management, the analytic framework by Hahn et al. (2010) was considered useful, as it visualizes the many different levels and dimensions in which trade-offs may take place. At the same time, it is possible to identify aspects that were not covered by the assessment. However, based on the experiences gained in this study, it is proposed that the framework could be extended by including a product and a technology level as a part of the organizational level. In the context of product- (or technology-) based sustainability assessment, many decisions and trade-off situations relate to selection of products or product properties, raw materials, logistics and suppliers, or locations of manufacturing. These are the decisions in which the trade-offs may materialize more often, whereas strategic decisions that cover the whole organization are perhaps taken less frequently. Especially in the case of large corporations, these decisions may have consequences that reach till the organizational, industrial and societal levels, due to the large volumes of products and materials that are handled, and large number of people employed or otherwise affected by these decisions.

Since the focus of life cycle thinking is on material flows, there is a strong spatial element within sustainability assessment. Studied environmental, economic and social impacts take place within physical locations, and assumed local context has a significant impact on the results. Potential trade-offs often materialize in different geographic locations or life cycle phases, as discussed in the case study II. Thus, it is proposed, that the geographic or spatial dimension could be added as the fourth dimension within the framework. This would be necessary, if the framework would be used in empirical studies, in addition to conceptual-level analyses.

The temporal dimension was not explicitly addressed within the case studies, and this can be considered as a clear limitation. The quantitative methods applied within

this study usually rely on availability of data, which restricts their usability for *ex-ante* type of assessments. Potential future impacts can be considered in LCA by using expert estimations and modified data collected from existing plants and pilot trials or demo plants, as was done in the CCS case in Study II. However, this makes communication of potential impacts more challenging, as more uncertainties are related to the results.

On the basis of the findings of this study, it is considered that sustainability assessment can increase understanding about the trade-offs between and within different sustainability aspects, but it is also necessary to acknowledge the limitations related to these methods. Some of the trade-offs can be measured or communicated in quantitative terms and by sticking to positivist and/or functionalist views related to the measurement process and in interpreting the results. However, as most of the quantitative assessments include a human component, and many choices have to be made during the assessments, more interpretive understanding of the assessment process and applied methods is necessary for understanding potential limitations related to the results, and to the reductionism that is necessary for measurement purposes. In addition, based on findings from the study IV, it seems that respondents of the information would prefer simplified information that would make their own judgement easier. However, for management purposes, it would be necessary to consider and to understand sustainability as a whole, including all the complexity that is related to the concept. Against this background, a major paradox is that a comprehensive sustainability assessment should not aim to make decision-making related to sustainability easier, but more complex.

5 Conclusions and discussion

5.1 Main conclusions

This study aimed at creating a synthesis based on existing theories and approaches related to sustainability management and sustainability assessment. The empirical part of the study was based on four practice-oriented sustainability assessment case studies that applied the principles of life cycle thinking. The study has considered the ability of sustainability assessment methods to provide the metrics and the knowledge that would be necessary for the purposes of sustainability management. In addition, the limitations and drawbacks related to those methods have been discussed. Specific focus of the study was on the use of life cycle thinking, in the context of sustainability assessment and management. The aim of the study was to respond to the following two research questions:

I What are the interlinkages between sustainability management, sustainability assessment and life cycle thinking?
II Can sustainability assessment increase understanding about potential trade-offs related to sustainability management?

This chapter summarizes the conclusions and contributions from this study, and presents recommendations for both researchers and practitioners working in the fields of sustainability assessment and management. Main conclusions and findings related to research question I are presented in Chapter 5.2. Chapter 5.3 summarizes the conclusions related to research question II. Quandaries related to the applied transdisciplinary research approach are discussed in Chapter 5.4. Recommendations and future research needs are presented in Chapter 5.5.

5.2 Identified interlinkages between the studied fields

As a response to the first research question, this study shows how sustainability assessment and sustainability management address similar questions, but from different point of views. Both are interested in solving sustainability challenges, and

apply a systems approach, but the research in these fields has remained separated, perhaps due to the different disciplinary backgrounds (engineering and social sciences).

One of the key findings of this study relates to the central role of measurements and metrics in both sustainability assessment and sustainability management. It seems that development of more efficient and more comprehensive methods is often proposed as a solution to challenges related to both measurement and management of sustainability (e.g., Dyllick & Muff, 2016; Gladwin et al., 1995; Sala et al., 2015; Shrivastava, 1995a). Multiple methods and measures for evaluating sustainability performance have been developed, but the field has remained fragmented in several distinct research communities that each use its own methods and definitions (Mura et al., 2018).

Standardization of methods and metrics has been proposed as a solution for problems related to transparency and comparability of the information (Montiel & Delgado-Ceballos, 2014). However, systematic analyses of commonly applied indices and frameworks have highlighted problems related to comparability of produced sustainability information (Boiral & Henri, 2017; Delmas & Doctori Blass, 2010). This is not only due to lack of data or transparency, but also due to the context-specific nature of many sustainability impacts, and the inherent complexity of sustainability as a concept, as pointed out by Boiral and Henri (2017). It is very difficult or even impossible to evaluate sustainability on a general level, without knowing the local context. The wider the scope of the assessment, the more there are factors that affect the result.

This study discusses, how use and development of different kinds of analytic methods has an important role within the field of sustainability assessment, but also within the field of management. From the evaluated sustainability management literature, one can make a conclusion that existing measures and available analytical tools have been criticized for mainly minimizing negative impacts of current, unsustainable practices (Ergene et al., 2020). These measures are considered to support business-as-usual type of activities, that do not really make a difference from sustainability point of view (Dyllick & Hockerts, 2002). However, the case studies included in the current thesis highlight how difficult it might be to find solutions that would be sustainable if the whole life cycle or all aspects of sustainability are considered.

Another practical challenge is that lack of absolute thresholds, definitions and data makes comparing performances of different products and technologies challenging. Stakeholders and decision-makers are interested in understanding the significance of the evaluated impacts, but providing such information is a rather complicated task that is difficult to do transparently. In addition, it would usually require making some value choices, which might feel inappropriate in the context of

the methods considered to represent objective results. Often the only practical way to do this comparison, is to make a reference with existing products, or previous performance, as this is the kind of data which is usually available for comparisons.

Because of the ambiguity related to the concept of sustainability and to the challenges related to measuring it, it has been proposed that sustainability should be assessed and managed considering different epistemological perspectives (Gladwin et al., 1995; Welford, 1998). In this study, life cycle thinking has been considered as an approach that combines methods and theories from both engineering and social sciences, and may apply both interpretive, and positivist approaches. Use of life cycle thinking does not necessarily mean using specific methods (such as LCA), but studying each case in a holistic manner, including both direct and indirect impacts, and extending the scope of the study from specific organizations to the whole life cycle or product system. It is compatible with the holistic systemic approach central to sustainability management (Starik & Kanashiro, 2013).

When considering the outcomes of the present study from positivist and interpretivist points of view, slightly different conclusions can be drawn. From a positivist perspective, the advantage of analytic methods relates to producing objective information that is based on scientific facts. However, as the case studies included in this thesis reveal, many assumptions and selections have to be made during the assessments. Many of these choices have an impact on the result. These selections range from formulation of the original research problem to the selection of the assessed options and sustainability aspects and their communication. Some of them may be forced due to practical constraints, but some of them are choices that relate to values. In addition, values relate to choices on how we deal with the practical constraints (such as lack of data, non-measurable or qualitative aspects), and how we in the first place start defining the problem we are studying, and selecting the things we are studying (Hertwich et al., 2000). Freidberg (2018) calls these contextual values, as they are related to the social and cultural context in which the assessment work occurs. Consequently, the produced "fact-based" information is (at least to some extent) socially constructed.

This is in line with the critique presented by Welford (1998, p. 9), regarding the impossibility to "separate social organization of knowledge production from the knowledge itself" (as discussed in Chapter 2). However, the discussion regarding social construction of knowledge has not been very common in the context of life cycle assessment studies, and values have rather been considered as a source of bias that may jeopardize the credibility of the method (Freidberg, 2018). In future, discussion about values and social aspects related to knowledge production should be encouraged, also in the context of method development, and among sustainability assessment practitioners.

From a more interpretivist perspective, the main advantage of analytic methods like LCA might not relate to producing "fact-based" information. Often, measurement is known to be imperfect, but this is easily forgotten when analysing and using the results. Based on the findings of this study, analytic methods are useful, since their use makes it necessary to consider in detail all related issues (inputs, outputs, life cycle phases and actors along the life cycle). Similarly, use of other structured methods like MCDM forces those involved in the process to take a closer look and consider all factors that have an impact on the studied issues. Systematic consideration of trade-offs together with in-depth discussions can be helpful for making difficult value choices. These methods may be burdensome to use due to extensive data collection and detailed modelling, but they usually reveal critical knowledge gaps and point out development needs and future research topics. This point reinforces the findings presented by Poikkimäki (2006), who highlighted the importance of learning that took place in the context of life cycle management projects.

Thus, use of structured, analytic methods for assessing complicated issues like sustainability has many benefits, but there are also weaknesses. The main weaknesses relate to the simplifications that are necessary during the assessment. Assessments produce a lot of information that usually includes trade-offs and uncertainties. However, the stakeholders would like to have the results presented as shortly and simply as possible, and in relation to something that is already familiar to them, as explained in the case study IV. This increases the need for reductionism. Dijk et al. (2017) actually describe sustainability assessment as a means for such reductionism, as the overall aim of the assessment should be to take a broad range of considerations and perspectives as an input, and process them into knowledge claims and recommendations. This corresponds to reductionism that Shrivastava (1994) named as one of the main weaknesses within the traditional organization theories that are unable to deal with complexity related to many environmental issues. For modelling or calculation purposes, complicated issues usually have to be simplified from multidimensional to one-dimensional, causal, cause and effect relationships. Furthermore, lack of relevant or comparable data often leads to narrowing down the scope of the study. Thus, both sustainability assessment and management are constrained by the reductionism that is related to keeping complex issues measurable and manageable.

However, according to the findings from case study IV, some level of reductionism may be necessary in order to make the results understandable to stakeholders. Previously, Pesonen and Horn (2013) have shown, how use of a streamlined sustainability assessment method was able to promote life cycle thinking and initiate change processes in different kinds of companies. Thus finding an

acceptable balance between comprehensiveness and simplicity remains a key challenge for both sustainability assessment and sustainability management.

Measuring is necessary for understanding the problems, but measuring is not necessarily enough to make sustainability manageable. At best, the assessments may help in understanding the complexity that is related to the topic, and identifying what needs to be changed or managed. At worst, assessments might support existing, business-as-usual habits, or even help legitimizing unsustainable activities. Focusing on only quantifiable and measurable information may provide too narrow understanding of the studied phenomenon, and lead to burden shifting and rebound effects. By extending the scope of the assessment from direct to indirect, and from purely quantitative to more qualitative means, it is possible to increase understanding of the studied problem. At the same time, information becomes more fragmented and less specific, and more difficult to communicate. Consequently, it becomes important to consider how organizations and individual decision-makers are able to use produced information, and if it helps them in making more sustainable choices.

Dijk et al. (2017) have highlighted how addressing wicked sustainability problems would require combining different epistemological approaches in the context of a sustainability assessment. Thus, it would be necessary to combine 'hard' scientific facts with stakeholder views to make the information usable for decision making (Dijk et al., 2017). In the context of the life cycle assessment, it has been recognized that methods such as normalization and weighing (which were applied in case studies III and IV) would be useful for communication and decision support (Pizzol et al., 2017). However, according to the findings presented by Pizzol and colleagues (2017), many experts consider that the use of these methods increases uncertainty in the assessments. The findings from the present study propose that it could be useful to explicitly integrate the principles of transdisciplinary research in the context analytic sustainability assessment methods as a way to combine fact-based and value-based information, and to increase the usability of the results for management and decision-making purposes.

Within the field of life cycle thinking, organization theories have been used for studying how life cycle assessment and life cycle thinking affect managers' reasoning and behaviour (Heiskanen, 2000; Rex & Baumann, 2007; 2008). These studies have shown how individual differences affect the way managers interpret the results of a life cycle assessment study, and whether this information encourages them on making changes to their organizations. Similarly, the cognitive framing approach by Hahn et al. (2014) proposes that applied cognitive frames might affect what kind of information managers are looking for in order to support their sustainability-related sense-making. Managers with the so-called business case frame were considered to favour measurable information describing well-defined topics, whereas managers with the paradoxical frame were considered to be more in

favour of comprehensive overviews of broader topics, but with less details describing specific aspects (Hahn et al., 2014). Consequently, it is proposed that when conducting a sustainability assessment, a balanced overview of both aspects should be considered. This will require using assessment approaches that use a combination of different kinds of methods and data, and apply different epistemological approaches.

5.3 Understanding trade-offs

The aim of the second research question was to consider the ability of sustainability assessment methods to increase understanding of potential trade-offs related to sustainability. Sustainability management research has been criticized for focusing too much on finding win-win solutions and balancing environmental and social aspects with economic needs (Dyllick & Muff, 2016; Ergene et al., 2020; Hahn et al., 2010, 2014). Similarly, sustainability assessment has been criticized for focusing too much on improving existing solutions (Sala et al., 2015) and relative improvements, instead of absolute reductions (Dyllick & Hockerts, 2002).

This study has applied the integrative view to corporate sustainability. The integrative view questions the ideal of finding a balance between environmental, economic and social aspects (Hahn et al., 2015, 2014). It recognizes the existence of tensions related to the concept of sustainability. A paradox view to sustainability proposes that understanding tensions and accepting the contradictory demands related to sustainability would be a necessary first step for successfully managing them (Smith & Tushman, 2005; Van der Byl & Slawinski, 2015). More empirical studies are needed to consider, how the paradox view is applied in practice (Van der Byl & Slawinski, 2015).

The case studies included in the present thesis have highlighted, how technological development includes impacts that can be both positive and negative. Here, the wider adoption of the paradox view within corporate sustainability and sustainability management could enable an open discussion of the tensions and trade-offs related to sustainability. Eventually, this could encourage more open disclosure of the information related to the environmental impacts of our activities, enabling more reliable assessments and motivating the engagement of all necessary actors.

This study contributes to the sustainability management literature related to paradoxes and trade-offs by discussing some of the paradoxes related to measuring and evaluating sustainability, based on findings of practical case studies related to sustainability assessment. Considering the central role that different measurements and metrics have in sustainability management, it is necessary for management scholars to understand the limitations related to available assessment methods. This study highlights how paradoxes are not only related to the concept of sustainability,

but also on the many different methods that are applied for measuring sustainability. Thus, it is argued that many of the existing challenges related to sustainability management cannot be addressed simply by developing more efficient metrics, but rather by increasing the understanding of the assessment process, and the need to conduct comprehensive assessments that combine both measurable and non-measurable aspects. In addition, it would be important to discuss different interpretations of sustainability and the values that are always present in the assessment process. While standardizing applied methods and metrics should be helpful for the assessment process, standardization will most likely not lead to standardized or fully comparable results, due to the context-specific nature of the assessments, and unspecific nature of sustainability as such (see also Dijk et al., 2017).

From a more practical perspective, this study has considered the ability of sustainability assessment case studies, and applied assessment methods to reveal potential trade-offs within and between different sustainability aspects, and different levels of assessment. The analysis was summarized using the analytic framework prepared by Hahn et al. (2010) (Table 3). The results from the case studies highlight how sustainability assessment is capable of identifying and measuring potential trade-offs especially within sustainability dimensions. Assessment methods that focus on physical flows can provide concrete evidence of practical problems and trade-offs that take place in different geographic locations, life cycle phases or different environmental impact categories. Thus, they can make an important contribution in bringing conceptual-level studies related to trade-offs closer to practical challenges in dealing with these trade-offs and their potential environmental, economic and social consequences to companies and to the society.

However, it is important to note that trade-offs are most easily discovered and communicated within impact categories that can be measured in quantitative terms. In practice, one method, such as the environmental LCA, is typically able to identify one kind of trade-offs, whereas identifying trade-offs between different aspects of sustainability requires using a combination of different assessment methods. However, in these cases the results from different methods are not directly compatible, which makes it more difficult to provide measured information, and to communicate the results. While methods such as multicriteria decision-making allow combining information produced from different methods and data sources, an aggregated numerical score as an end-result is not very informative for communication purposes.

The importance of addressing sustainability challenges and trade-offs that take place at the system level has been highlighted by many authors. The “big disconnect” between sustainable development as a societal level goal, and the focus of sustainability management as an organizational goal has been identified as one of

the main challenges for sustainability management (Dyllick & Muff, 2016). This is a challenge for which the product based sustainability assessment methods, such as LCA, cannot easily answer. Measuring impacts that take place at different levels is a continuous challenge, as the assessment methods typically focus on one level at a time, in order to manage all necessary data and assumptions. Achieving a comprehensive understanding often requires using different kinds of methods that focus on impacts that take place at different levels.

It has been proposed that instead of relative-, company- or product-level sustainability assessments, planetary boundaries[7] should be considered as a reference for setting company-level sustainability goals (Haffar & Searcy, 2018; Whiteman et al., 2013). The development of the absolute sustainability assessment methods is an attempt to respond to this call. The aim of the absolute sustainability assessment methods is to quantify the environmental impacts of companies in relation to their share of the global carrying capacity, which can be determined, for example, by using the planetary boundaries framework (Bjørn et al., 2020). Although a few examples of practical case studies that evaluate company-level sustainability performance in relation to the global thresholds have been published (Ryberg, Bjerre, Nielsen, & Hauschild, 2020), many open questions remain. Important questions include, for example, the principles that should be used for sharing the global carrying capacity between different actors (Bjørn et al., 2020). In addition, it is important to note that even such absolute measures can be criticized for the same kind of reductionism that has been related to other current company-level approaches (see eg. Isil & Hernke, 2017).

However, the findings from the present study highlight how putting the results into a certain perspective might be needed to make the results understandable. The absolute measures of environmental performance in relation to the earth's carrying capacity might be effective in illustrating the magnitude of change that is needed at the company level. Thus, there might be a need accept reductionism and the uncertainty that might be included in the assessment results to support decision-making towards sustainability. This will be a continuous challenge for sustainability researchers, who will need to struggle between the dilemma of combining various aspects and assumptions from different sciences, combining facts and values, keeping the results scientifically valid, being transparent about everything and making the results understandable to the public.

[7] The planetary boundaries concept defines nine global boundaries which should not be exceeded in order not to risk the functioning of the global ecosystems. What is alarming is that already five of the nine planetary boundaries for safe operating space have been exceeded, two of them (global warming and integrity of biodiversity) already being on the zone of high risk for negative consequences (Steffen et al., 2015).

Companies willing to invest in more sustainable practices should place much more emphasis and resources for systematic research and development activities related to sustainability assessment of their own products and activities. With simplified assessments it is possible to come up with simplified solutions that may have some impact, but which are usually not enough to really change the way business is done or products are manufactured. Sustainability assessments may serve as an important learning exercise and increase understanding of the sustainability challenges that need to be addressed. However, this requires systematic and careful application of different assessment methods, and a thorough consideration of the results from different point of views. In addition, it will require open discussions and communication about the values and trade-offs that usually cannot be avoided, along with close cooperation with other life cycle actors.

In the context of life cycle assessment, Fullana i Palmer (2011) has pointed out how LCA should not be used for "providing the right answers", but rather for "finding the right questions". Consequently, a sustainability assessment should be considered as a continuous process that points out data gaps and development needs, and highlights potential tensions and trade-offs that would need to be addressed in order to become more sustainable. Achieving one specific goal or threshold would mean setting new and more ambitious or comprehensive targets. If we consider sustainable development as an ideal concept that can never be fully achieved, it means that there is always room for improvement.

5.4 Quandaries related to transdisciplinary research approach

This chapter focuses on considering, how some of the common challenges related to transdisciplinary research were handled in this thesis. Wickson et al. (2006) present three quandaries and challenges that are typical for transdisciplinary research, namely *integration, reflection and paradox.* They recommend all researchers who apply transdisciplinary practices to consider the implications of these conceptual boundaries for their own research. In transdisciplinary research, *integration* can and should take place at different levels, including integration of different epistemologies, integration of theory and practice, and finally, the integration of researchers into their research context (Wickson et al., 2006). Integration of epistemologies does not mean developing a single, unified truth in accordance with disciplines, but rather integrating different knowledge and building new knowledge by looking for coherences, correspondences and identifying joint patterns across diverse disciplines and discourses (ibid).

This study has aimed at identifying gaps and pointing out joint interests, challenges and complementary elements between the sustainability management and

sustainability assessment literatures. When combining different research approaches, it is not possible to examine very deeply the theories of one discourse, and it might be that much interesting or relevant research has been ignored. This challenge is even more significant because all the research fields discussed in this study are diverse and fragmented within several distinct research communities (see eg. Montiel & Delgado-Ceballos, 2014; Mura et al., 2018; Pfeffer, 1997), making it extremely difficult to make any kind of synthesis without coming to rather harsh generalizations. In addition, while it is acknowledged that sustainability includes environmental, economic and social aspects, this study has focused mainly on environmental sustainability, mostly due to practical reasons and to the need to keep the study manageable. However, the aim of this study has been to point out potential avenues for future research, by looking at the commonalities between the studied areas. The study has identified how both positivist and interpretivist approaches are present in sustainability-related research and practice, and it is considered necessary to work with both approaches also in future studies. As such, the transdisciplinary research approach is considered useful in this context, as it allows handling both in one study.

According to Wickson et al., (2006), researchers should aim at engaging with both theory and practice, visiting and informing both areas to the point where they are integrated or resonant. This is a challenging goal for one thesis, and it is difficult to evaluate at which point this integration is finally achieved. While this study does not build new theory, it provides some building blocks for further developing and complementing the sustainability management theories, and proposes how the idea of cognitive frameworks could be used to enrich the practices related to sustainability assessment, and for better addressing the information needs of managers and industrial experts dealing with sustainability.

While testing these ideas in practice remains a challenge for future research, the experiences gained by the author during several years of sustainability assessment projects have indicated that something similar to the assumed business case frame and to the paradoxical frame do exist in practice. This experience was one of the starting points of this study, and is reflected in the title “What can be measured can be managed”. This common saying (without the question mark at the end) is sometimes repeated in the context of LCA method development and by business representatives investing in LCA development. While most persons working with LCA acknowledge the challenges related to measuring sustainability, it often happens that these challenges are ignored by the respondents of the information. As often (but not always), the decision-makers would prefer simplified answers and results that are easy to incorporate within the current system (as also highlighted by the results of study IV related to communication of LCIA results). Consequently, it may happen that the complexities and non-measurable aspects (that are almost always somehow present), get ignored in the end, as there is no numerical value that could be communicated for

those aspects (see e.g. case study III). And at the same time, it is acknowledged that without such simplifications and measurements, it would be likely that even less sustainability information would be used in decision-making.

Thus, the question mark added in the title of this study calls for the need to critically think about complexities and uncertainties related to the possibilities in measuring and managing such a complex issue like sustainability. At the same time, the question mark underlines the importance of using all possible efforts for developing better methods and theories for both assessment and management purposes. As it is necessary to integrate sustainability information in all future decision-making, this information should be based on studied "facts", rather than mere assumptions about sustainable practices. Most importantly, these "facts" should aim at increasing our knowledge and understanding about sustainability.

The above discussion highlights the third aspect of *integration*, which relates to the researcher being tightly embedded within the research process. This embeddedness relates to challenges in critically observing one's own activities and the research process, while being an active part of it. Thus, the second challenge related to transdisciplinary research, as described by Wickson et al. (2006), relates to the need for continuous *reflection.* Reflective practices are important for reasons of transparency, and in order to understand how researchers' own values, beliefs and assumptions have affected the research process (ibid). In addition, reflection relates to the need for observing different bodies of knowledge in the light of other bodies of knowledge, rather than only accepting one of them as the only truth.

The outcome of this study is without a doubt affected by the experiences and practices of the researcher, as the starting point of the study is based on the empirical experience of the author, building on the findings of the case studies. However, this relation and starting point has been openly described within the study. On the other hand, it is most likely impossible to openly describe or even recognize some of the implicit assumptions that affect one's interpretation. In this case, the background of the author as a qualitative researcher has most likely affected the research process described in the current study. It is considered that that experiences gained by the researcher during several years have made it possible to also critically analyse some of the prevailing practices, and the challenges that seem to be repeating from one assessment project to another. Additionally, theoretical knowledge and findings were used for building and framing the research problem and identifying a research gap that would be also scientifically valid. However, it is likely that there are also blind spots related to existing practices. And it is likely that such spots cannot be easily identified by an embedded researcher. On the other hand, all the cases have been conducted with different groups of colleagues, and some reflection has been required in each case, and many of the central assumptions have been discussed and questioned in the context of each study.

The third important challenge and quandary related to transdisciplinary research, as described by Wickson et al. (2006), relates to the existence of *paradoxes* that are an essential part of transdisciplinary research. Wickson and colleagues (2006) consider that the need to handle paradoxes may encourage researchers towards conceptual freedom and creativity in building their research. Additionally, they propose that revealing paradoxes could be included as one of the quality evaluation criteria related to transdisciplinary research.

This study has discussed some of the paradoxes related to both sustainability assessment and sustainability management. While this study has not been able to solve the challenge related to the existing paradoxes, it has proposed some ideas on how they could be better handled in future studies, and also in practice, by combining some of the discussed theories related to sustainability management and sustainability assessment. In addition, it is considered that better understanding of the assessment process and the paradoxes related to measuring and assessing sustainability would be crucial for sustainability management. This is important since secondary data is commonly applied by management scholars for evaluating sustainability performance (Montiel & Delgado-Ceballos, 2014).

In this thesis, a central paradox is that quantitative methods (such as LCA) originating from environmental engineering, are used to quantify environmental impacts and provide "fact-based" information about sustainability. And at the same time, it is argued that measuring sustainability impacts is challenging, and that the resulting information is always uncertain, and can rarely be used to make absolute judgments about sustainability of a product or a technology. This is due to sustainability being a socially constructed, context- and value-based concept, for which absolute measures rarely exist. However, it is still considered necessary to conduct such assessments, since even if the information created is usually uncertain and presented "facts" could be questioned, use of these methods increases our knowledge of the studied subject, and this knowledge is necessary in order to create learning. However, it is necessary to pay more attention on how this information is interpreted and communicated.

5.5 Recommendations and future research needs

This study contributes to existing literature on sustainability management by increasing understanding about practical challenges and constraints related to measuring sustainability and communicating the results. This is considered important, taking into account the central role that measurements and metrics have within the literature on sustainability management. Previous research has pointed out how there is a lack of systematic methods for evaluating and measuring trade-offs related to sustainability (Hahn et al., 2010). In this study, it is considered that there

are plenty of methods that could be used for this purpose. However, these methods have not yet been commonly applied by management scholars. This study has addressed this gap by considering the ability of existing sustainability assessment methods and generic decision-support tools like LCA and MCDM to identify trade-offs related to different aspects of sustainability management.

The study concludes that existing methods are useful for identifying trade-offs, but it is necessary to understand their limitations. Simply looking at measurable aspects provides too narrow understanding of many sustainability impacts, and may hide important interlinkages, trade-offs and rebound effects. However, at the same time it is acknowledged that measuring is important and useful in the context of sustainability, as it makes it necessary to study all the details that are related to the topic. Thus, it usually reveals important knowledge gaps and areas that require further studies. In addition, it connects the assessment to specific locations and environments in which the actual impacts may take place. This is a relevant topic for sustainability management research, since lack of environmental data and limited use of natural sciences have been acknowledged as one of the development needs within this emerging field (e.g., Etzion, 2007; Montiel & Delgado-Ceballos, 2014) Shrivastava and Kennelly (2013) have even proposed, that the "placeless" character of corporate sustainability research has alienated the field from the actual physical and social impacts that take place locally.

Although it will be important to continue the development of more precise methods and tools, it is equally important to start considering how we make decisions and based on what kind of information. Decision-makers and researchers should be able to digest both quantitative and qualitative information, accept different kind of interpretations of sustainability and the uncertainty that is related to the topic. No matter how precise or perfect assessment methods we develop, they do not help the fact that sustainability is not an easy task to manage. It could even be argued that frequently calling for new metrics and methods is actually one of the reasons that might postpone the problem rather than solve it.

We already have plenty of assessment methods available, and as the case studies included in this thesis show, it is possible to use existing methods for analysing and understanding sustainability impacts. The more we know, the more questions we will probably have and the more precise methods we would need to develop before we can start acting. However, in the context of sustainability, it seems necessary to accept some uncertainty. In their model for organizational inaction on climate change, Slawinski et al. (2017) propose that low tolerance for uncertainty may lead managers to ignore uncertain information, and focus their activities on aspects from which short-term benefits may be achieved. This is detrimental for activities like climate change mitigation, which would require heavy investments in the short term, but promises only uncertain benefits somewhere in the long term.

In future sustainability assessment studies, management theories should be used for considering, how uncertainty and ambiguousness related to all assessments should be handled and made more visible in the context of sustainability assessment. In addition, it should be considered, how acknowledging this uncertainty might affect managerial decision-making and stakeholder communication. The cognitive framework approach presented by Hahn et al. (2014) seems promising in this context, taking into account how individual managers and decision-makers handle uncertainty and complexity related to sustainability.

Future research could consider, how the theory of managerial sense making using the business case frame and the paradoxical frame (Hahn et al., 2014) could be applied when presenting the results of a sustainability assessment. This would be important, in order to understand, how to present the complexity related to many sustainability issues in a way that promotes finding creative and radical, yet rapidly implementable solutions in practice. In addition, more transdisciplinary studies focusing on LCT and LCM should be conducted, as it seems that the studies related to sustainability management, sustainability performance measurement and life cycle assessment have mostly remained separated and segregated within their own fields. The findings of this thesis show, how these fields share many commonalities, and could benefit from closer cooperation. In future, it will be necessary to increase the use of sustainability assessment methods in the context of sustainability management and corporate sustainability research, and extend the scope of the studies from organizations to life cycles and value chains. As one researcher can rarely master all necessary methods and theories or disciplines, cooperation between researchers is encouraged.[8]

The findings from this study indicate that practice-oriented transdisciplinary research provides a framework that allows combining methods and approaches that originate from different disciplinary practices. Previously, Williams et al. (2017, p. 878) have recommended transdisciplinary research as a means for better understanding "sustainability from holistic systems perspective". Focusing on challenges identified in concrete case studies may lower the barrier in applying new and creative approaches, despite potential epistemological mismatches (Wickson et al., 2006). Additionally, transdisciplinary research accepts the paradoxes that are evident in both sustainability management and sustainability assessment. However, integrating all these contradictory aspects in the practice of sustainability assessment and management will most likely remain challenging.

[8] For example, this transdisciplinary study would not have been possible without years of cooperation with several researchers that each have their own areas of specialization, ranging from life cycle assessment and multicriteria decision-making to environmental sciences, various fields of engineering, metallurgy and sociology.

Abbreviations

AHP	analytic hierarchy process
CCS	carbon capture and storage
GHG	greenhouse gas
ICT	information and communication technologies
IPBES	the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
IPCC	the Intergovernmental Panel on Climate Change
LCA	life cycle assessment
LCIA	life cycle impact assessment
LCM	life cycle management
LCT	life cycle thinking
MAVT	multi-attribute value theory
MCDM	multicriteria decision-making
OS	organization studies
PESTEL	analysis of Political, Economic, Social, Technological, Environmental and Legal aspects

List of References

Bansal, P. (2019). Sustainable Development in an Age of Disruption. *Academy of Management Discoveries*, *5*(1), 8–12. https://doi.org/10.5465/amd.2019.0001

Bansal, P., & Gao, J. (2006). Building the future by looking to the past: Examining research published on organizations and environment. *Organization and Environment*, *19*(4), 458–478. https://doi.org/10.1177/1086026606294957

Baumann, H., Lindahl, M., Scandelius, C., Schmidt, K., & Sonnemann, G. (2018). Preface: Recognizing management in LCM. *The International Journal of Life Cycle Assessment*, *23*(7), 1351–1356. https://doi.org/10.1007/s11367-017-1368-x

Bettencourt, L. M. A., & Kaur, J. (2011). Evolution and structure of sustainability science. *Proceedings of the National Academy of Sciences*, *108*(49), 19540–19545. https://doi.org/10.1073/pnas.1102712108

Bjørn, A., Chandrakumar, C., Boulay, A.-M., Doka, G., Fang, K., Gondran, N., … Ryberg, M. (2020). Review of life-cycle based methods for absolute environmental sustainability assessment and their applications. *Environmental Research Letters*, *15*(8), 083001. https://doi.org/10.1088/1748-9326/ab89d7

Boiral, O., & Henri, J.-F. (2017). Is Sustainability Performance Comparable? A Study of GRI Reports of Mining Organizations. *Business & Society*, *56*(2), 283–317. https://doi.org/10.1177/0007650315576134

Delmas, M. A., Etzion, D., & Nairn-Birch, N. (2013). Triangulating Environmental Performance: What Do Corporate Social Responsibility Ratings Really Capture? *Academy of Management Perspectives*, *27*(3), 255–267. https://doi.org/10.5465/amp.2012.0123

Delmas, M., & Doctori Blass, V. (2010). Measuring corporate environmental performance: the trade-offs of sustainability ratings. *Business Strategy and the Environment*, *19*(4), 245–260. https://doi.org/10.1002/bse.676

Dijk, M., de Kraker, J., van Zeijl-Rozema, A., van Lente, H., Beumer, C., Beemsterboer, S., & Valkering, P. (2017). Sustainability assessment as problem structuring: three typical ways. *Sustainability Science*, *12*(2), 305–317. https://doi.org/10.1007/s11625-016-0417-x

Dyllick, T., & Hockerts, K. (2002). Beyond the business case for corporate sustainability. *Business Strategy and the Environment*, *11*(2), 130–141. https://doi.org/10.1002/bse.323

Dyllick, T., & Muff, K. (2016). Clarifying the Meaning of Sustainable Business. *Organization & Environment*, *29*(2), 156–174. https://doi.org/10.1177/1086026615575176

Ergene, S., Banerjee, S. B., & Hoffman, A. J. (2020). (Un)Sustainability and Organization Studies: Towards a Radical Engagement. *Organization Studies*, 017084062093789. https://doi.org/10.1177/0170840620937892

Etzion, D. (2007). Research on Organizations and the Natural Environment, 1992-Present: A Review. *Journal of Management*, *33*(4), 637–664. https://doi.org/10.1177/0149206307302553

European Commission. (2003). *Integrated Product Policy - Building on Environmental Life-Cycle Thinking (COM/2003/0302 final)*. Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52003DC0302

European Commission. (2013). *Building the Single Market for Green Products - Facilitating better information on the environmental performance of products and organisations. COM(2013) 196 final*. Retrieved from https://ec.europa.eu/transparency/regdoc/rep/1/2013/EN/1-2013-196-EN-F1-1.Pdf

European Commission. (2015). *Closing the Loop – An EU action plan for the Circular Economy. COM(2015) 614 final*. Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52015DC0614

European Commission. (2016). *Next steps for a sustainable European future. European action for sustainability. COM(2016) 739 final*. Retrieved from European Commission website: https://ec.europa.eu/europeaid/sites/devco/files/communication-next-steps-sustainable-europe-20161122_en.pdf

Finnveden, G. (1997). Valuation methods within LCA - Where are the values? *The International Journal of Life Cycle Assessment*, *2*(3), 163. https://doi.org/10.1007/BF02978812

Freidberg, S. (2018). From behind the curtain: talking about values in LCA. *International Journal of Life Cycle Assessment*, *23*(7), 1410–1414. https://doi.org/10.1007/s11367-015-0879-6

Fullana i Palmer, P., Puig, R., Bala, A., Baquero, G., Riba, J., & Raugei, M. (2011). From Life Cycle Assessment to Life Cycle Management. *Journal of Industrial Ecology*, *15*(3), 458–475. https://doi.org/10.1111/j.1530-9290.2011.00338.x

Funtowicz, S. O., & Ravetz, J. R. (1993). Science for the post-normal age. *Futures*, *25*(7), 739–755. https://doi.org/10.1016/0016-3287(93)90022-L

Gladwin, T. N., Kennelly, J. J., & Krause, T.-S. (1995). Shifting Paradigms for Sustainable Development: Implications for Management Theory and Research. *The Academy of Management Review*, *20*(4), 874. https://doi.org/10.2307/258959

Godfray, H. C. J., Beddington, J. R., Crute, I. R., Haddad, L., Lawrence, D., Muir, J. F., … Toulmin, C. (2010). Food Security: The Challenge of Feeding 9 Billion People. *Science*, *327*(5967), 812–818. https://doi.org/10.1126/science.1185383

Goulart Coelho, L. M., Lange, L. C., & Coelho, H. M. (2017). Multi-criteria decision making to support waste management: A critical review of current practices and methods. *Waste Management & Research*, *35*(1), 3–28. https://doi.org/10.1177/0734242X16664024

Guinée, J. B., Heijungs, R., Huppes, G., Zamagni, A., Masoni, P., Buonamici, R., … Rydberg, T. (2011). Life cycle assessment: past, present, and future. *Environmental Science & Technology*, *45*(1), 90–96. https://doi.org/10.1021/es101316v

Hacking, T., & Guthrie, P. (2008). A framework for clarifying the meaning of Triple Bottom-Line, Integrated, and Sustainability Assessment. *Environmental Impact Assessment Review*, *28*(2–3), 73–89. https://doi.org/10.1016/j.eiar.2007.03.002

Haffar, M., & Searcy, C. (2017). Classification of Trade-offs Encountered in the Practice of Corporate Sustainability. *Journal of Business Ethics*, *140*(3), 495–522. https://doi.org/10.1007/s10551-015-2678-1

Haffar, M., & Searcy, C. (2018). Target-setting for ecological resilience: Are companies setting environmental sustainability targets in line with planetary thresholds? *Business Strategy and the Environment*, *27*(7), 1079–1092. https://doi.org/10.1002/bse.2053

Hahn, T., Figge, F., Aragón-Correa, J. A., & Sharma, S. (2017). Advancing Research on Corporate Sustainability. *Business & Society*, *56*(2), 155–185. https://doi.org/10.1177/0007650315576152

Hahn, T., Figge, F., Pinkse, J., & Preuss, L. (2010). Trade-offs in corporate sustainability: you can't have your cake and eat it. *Business Strategy and the Environment*, *19*(4), 217–229. https://doi.org/10.1002/bse.674

Hahn, T., Figge, F., Pinkse, J., & Preuss, L. (2018). A Paradox Perspective on Corporate Sustainability: Descriptive, Instrumental, and Normative Aspects. *Journal of Business Ethics*, *148*(2), 235–248. https://doi.org/10.1007/s10551-017-3587-2

Hahn, T., Pinkse, J., Preuss, L., & Figge, F. (2015). Tensions in Corporate Sustainability: Towards an Integrative Framework. *Journal of Business Ethics*, *127*(2), 297–316. https://doi.org/10.1007/s10551-014-2047-5

Hahn, T., Preuss, L., Pinkse, J., & Figge, F. (2014). Cognitive Frames in Corporate Sustainability : Managerial Sensemaking With Paradoxical and. *Academy of Management Review*, *39*(4), 463–487.

Hart, S. L. (1995). Natural-Resource-Based View of the Firm. *Academy of Management Review*, *20*, 986–1014.

Heiskanen, E. (2000). Managers' interpretations of LCA: enlightenment and responsibility or confusion and denial? *Business Strategy and the Environment*, *9*(4), 239–254. https://doi.org/10.1002/1099-0836(200007/08)9:4<239::AID-BSE250>3.0.CO;2-6

Heiskanen, E. (2002). The institutional logic of life cycle thinking. *Journal of Cleaner Production*, *10*, 427–437.

Hertwich, E. G., Hammitt, J. K., & Pease, W. S. (2000). A theoretical foundation for life-cycle assessment: Recognizing the role of values in environmental decision making. *Journal of Industrial Ecology*, *4*(1), 13–28. https://doi.org/10.1162/108819800569267

Hirsch Hadorn, G., Hoffmann-Riem, H., Biber-Klemm, S., Grossenbacher-Mansuy, W., Joye, D., Pohl, C., … Zemp, E. (Eds.). (2008). *Handbook of Transdisciplinary Research*. https://doi.org/10.1007/978-1-4020-6699-3

Hoffman, A. J. (2003). Linking Social Systems Analysis To The Industrial Ecology Framework. *Organization & Environment*, *16*(1), 66–86. https://doi.org/10.1177/1086026602250219

Hörisch, J., Freeman, R. E., & Schaltegger, S. (2014). Applying Stakeholder Theory in Sustainability Management. *Organization & Environment*, *27*(4), 328–346. https://doi.org/10.1177/1086026614535786

Independent Group of Scientists appointed by the Secretary-General. (2019). *Global Sustainable Development Report 2019: The Future is Now – Science for Achieving Sustainable Development*. Retrieved from https://sustainabledevelopment.un.org/content/documents/24797GSDR_report_2019.pdf

IPBES. (2019). *Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. Advance Unedited version, 6 May 2019.* Retrieved from https://www.ipbes.net/news/ipbes-global-assessment-summary-policymakers-pdf

IPCC. (2018). Summary for Policymakers. In V. Masson-Delmotte, P. Zhai, H. O. Pörtner, D. Roberts, S. J., P. R. Shukla, … T. Waterfield (Eds.), *Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change,* (p. 32). Retrieved from https://www.ipcc.ch/sr15/chapter/summary-for-policy-makers/

Isil, O., & Hernke, M. T. (2017). The Triple Bottom Line: A Critical Review from a Transdisciplinary Perspective. *Business Strategy and the Environment*, *26*(8), 1235–1251. https://doi.org/10.1002/bse.1982

ISO 14040. (2006). *Environmental management - Life cycle assessment - Principles and framework*.

Jennings, P. D., & Zandbergen, P. A. (1995). Ecologically Sustainable Organizations: An Institutional Approach. *Academy of Management Review*, *20*(4), 1015–1052. https://doi.org/10.5465/amr.1995.9512280034

Kallio, T. J., & Nordberg, P. (2006). The Evolution of organizations and natural environment discourse: Some critical remarks. *Organization and Environment*, *19*(4), 439–457. https://doi.org/10.1177/1086026606294955

Kangas, J., Kangas, A., Leskinen, P., & Pykäläinen, J. (2001). MCDM methods in strategic planning of forestry on state-owned lands in Finland: applications and experiences. *Journal of Multi-Criteria Decision Analysis*, *10*(5), 257–271. https://doi.org/10.1002/mcda.306

Kates, R. W. (2011). What kind of a science is sustainability science? *Proceedings of the National Academy of Sciences*. https://doi.org/10.1073/pnas.1116097108

Kates, Robert W., Clark, W. C., Corell, R., Hall, J. M., Jaeger, C. C., Lowe, I., & McCarthy, J. J. (2001). ENVIRONMENT AND DEVELOPMENT: Sustainability Science. *Science*, *292*(5517), 641–642. https://doi.org/10.1126/science.1059386

Kemp, R., & Martens, P. (2007). Sustainable development: how to manage something that is subjective and never can be achieved? *Sustainability: Science, Practice and Policy*, *3*(2), 5–14. https://doi.org/10.1080/15487733.2007.11907997

Kiker, G. A., Bridges, T. S., Varghese, A., Seager, T. P., & Linkov, I. (2005). Application of Multicriteria Decision Analysis in Environmental Decision Making. *Integrated Environmental Assessment and Management*, *1*(2), 95. https://doi.org/10.1897/IEAM_2004a-015.1

Korhonen, J., von Malmborg, F., Strachan, P. A., & Ehrenfeld, J. R. (2004). Management and policy aspects of industrial ecology: an emerging research agenda. *Business Strategy and the Environment*, *13*(5), 289–305. https://doi.org/10.1002/bse.415

Krohn, W. (2008). Learning from Case Studies. In G. Hirsch Hadorn, H. Hoffmann-Riem, S. Biber-Klemm, W. Grossenbacher-Mansuy, D. Joye, C. Pohl, … E. Zemp (Eds.), *Handbook of Transdisciplinary Research* (pp. 369–383). https://doi.org/10.1007/978-1-4020-6699-3_24

Lang, D. J., Stauffacher, M., Swilling, M., Wiek, A., Moll, P., Bergmann, M., … Martens, P. (2012). Transdisciplinary research in sustainability science: practice, principles, and challenges. *Sustainability Science*, *7*(S1), 25–43. https://doi.org/10.1007/s11625-011-0149-x

Lazarevic, D., & Martin, M. (2018). Life cycle assessment calculative practices in the Swedish biofuel sector: Governing biofuel sustainability by standards and numbers. *Business Strategy and the Environment*, *27*(8), 1558–1568. https://doi.org/10.1002/bse.2214

Linnanen, L., Bostrom, T., & Miettinen, P. (1995). Life Cycle Management: Integrated approach towards corporate environmental issues. *Business Strategy and the Environment*, *4*, 117–127.

Linnenluecke, M. K., & Griffiths, A. (2013). Firms and sustainability: Mapping the intellectual origins and structure of the corporate sustainability field. *Global Environmental Change*, *23*(1), 382–391. https://doi.org/10.1016/j.gloenvcha.2012.07.007

Margolis, J. D., & Walsh, J. P. (2003). Misery Loves Companies : Rethinking Social Initiatives by Business. *Administrative Science Quarterly*, *48*(2), 268–305.

Martens, P. (2006). Sustainability: science or fiction? *Sustainability: Science, Practice & Policy*, *2*(1), 36–41. Retrieved from https://www.tandfonline.com/doi/abs/10.1080/15487733.2006.11907976

Moeller, C., Sauerborn, J., de Voil, P., Manschadi, A. M., Pala, M., & Meinke, H. (2014). Assessing the sustainability of wheat-based cropping systems using simulation modelling: sustainability = 42? *Sustainability Science*, *9*(1), 1–16. https://doi.org/10.1007/s11625-013-0228-2

Montiel, I., & Delgado-Ceballos, J. (2014). Defining and Measuring Corporate Sustainability: Are We There Yet? *Organization and Environment*, *27*(2), 113–139. https://doi.org/10.1177/1086026614526413

Morrison-Saunders, A., & Pope, J. (2013). Conceptualising and managing trade-offs in sustainability assessment. *Environmental Impact Assessment Review*, *38*, 54–63. https://doi.org/10.1016/j.eiar.2012.06.003

Mura, M., Longo, M., Micheli, P., & Bolzani, D. (2018). The Evolution of Sustainability Measurement Research. *International Journal of Management Reviews*, *20*(3), 661–695. https://doi.org/10.1111/ijmr.12179

Ness, B., Urbel-Piirsalu, E., Anderberg, S., & Olsson, L. (2007). Categorising tools for sustainability assessment. *Ecological Economics*, *60*(3), 498–508. https://doi.org/10.1016/j.ecolecon.2006.07.023

Nilsson-Lindén, H., Baumann, H., & Rex, E. (2019). LCM development: focusing on the LC promoters and their organizational problem-solving. *The International Journal of Life Cycle Assessment*, *24*(2), 297–309. https://doi.org/10.1007/s11367-018-1523-z

Nilsson-Lindén, H., Baumann, H., Rosén, M., & Diedrich, A. (2018). Organizing life cycle management in practice: challenges of a multinational manufacturing corporation. *The International Journal of Life Cycle Assessment*, *23*(7), 1368–1382. https://doi.org/10.1007/s11367-014-0818-y

Pesonen, H. L., & Horn, S. (2013). Evaluating the Sustainability SWOT as a streamlined tool for life cycle sustainability assessment. *International Journal of Life Cycle Assessment*, *18*(9). https://doi.org/10.1007/s11367-012-0456-1

Petti, L., Serreli, M., & Di Cesare, S. (2018). Systematic literature review in social life cycle assessment. *The International Journal of Life Cycle Assessment*, *23*(3), 422–431. https://doi.org/10.1007/s11367-016-1135-4

Pfeffer, J. (1997). *New Directions for Organization Theory: Problems and prospects*. Oxford University Press, Incorporated.

Pihkola, H., Pajula, T., Federley, M., Myllyoja, J., Tapia, C., Ritthoff, M., & Saurat, M. (2017). *Sustainability assessment in the process industries - Current practice and paths for future development: Conclusions and recommendations from the SAMT project*. Retrieved from https://www.vtt.fi/inf/pdf/technology/2017/T299.pdf

Pizzol, M., Laurent, A., Sala, S., Weidema, B., Verones, F., & Koffler, C. (2017). Normalisation and weighting in life cycle assessment: quo vadis? *International Journal of Life Cycle Assessment*, *22*(6), 853–866. https://doi.org/10.1007/s11367-016-1199-1

Pohl, C., & Hirsch Hadorn, G. (2008). Core Terms in Transdisciplinary Research. In G. Hirsch Hadorn, H. Hoffmann-Riem, S. Biber-Klemm, W. Grossenbacher-Mansuy, D. Joye, C. Pohl, & E. Zemp (Eds.), *Handbook of Transdisciplinary Research* (pp. 427–432). https://doi.org/10.1007/978-1-4020-6699-3_28

Poikkimäki, S. (2006). *Look Closer to see Further – Exploring environmental life cycle management, LCM* (University of Jyväskylä). Retrieved from https://jyx.jyu.fi/dspace/bitstream/handle/123456789/13194/9513925633.pdf?sequence=1

Pope, J., Bond, A., Hugé, J., & Morrison-Saunders, A. (2017). Reconceptualising sustainability assessment. *Environmental Impact Assessment Review*, *62*, 205–215. https://doi.org/10.1016/j.eiar.2016.11.002

Rex, E., & Baumann, H. (2007). Individual adaptation of industry LCA practice: Results from two case studies in the Swedish forest products industry. *The International Journal of Life Cycle Assessment*, *12*(4), 266–271. https://doi.org/10.1007/s11367-007-0330-8

Rex, E., & Baumann, H. (2008). Implications of an interpretive understanding of LCA practice. *Business Strategy and the Environment*, *17*(7), 420–430. https://doi.org/10.1002/bse.633

Ryberg, M. W., Bjerre, T. K., Nielsen, P. H., & Hauschild, M. (2020). Absolute environmental sustainability assessment of a Danish utility company relative to the Planetary Boundaries. *Journal of Industrial Ecology*, jiec.13075. https://doi.org/10.1111/jiec.13075

Sala, S., Ciuffo, B., & Nijkamp, P. (2015). A systemic framework for sustainability assessment. *Ecological Economics*, *119*, 314–325. https://doi.org/10.1016/j.ecolecon.2015.09.015

Sala, S., Farioli, F., & Zamagni, A. (2013). Progress in sustainability science: lessons learnt from current methodologies for sustainability assessment: Part 1. *The International Journal of Life Cycle Assessment*, *18*(9), 1653–1672. https://doi.org/10.1007/s11367-012-0508-6

Schaltegger, S., Beckmann, M., & Hansen, E. G. (2013). Transdisciplinarity in Corporate Sustainability: Mapping the Field. *Business Strategy and the Environment*, *22*(4), 219–229. https://doi.org/10.1002/bse.1772

Scott, R. W. (1998). *Organizations. Rational, Natural and Open Systems* (Fourth edi). Upper Sadle River, New Jersey: Prentice Hall.

Seager, T. P. (2008). The sustainability spectrum and the sciences of sustainability. *Business Strategy and the Environment*. https://doi.org/10.1002/bse.632

Searcy, C. (2016). Measuring Enterprise Sustainability. *Business Strategy and the Environment*, *25*(2), 120–133. https://doi.org/10.1002/bse.1861

Seppälä, J., Basson, L., & Norris, G. A. (2002). Decision Analysis Frameworks for Life-Cycle Impact Assessment. *Journal of Industrial Ecology*, *5*(4), 45–68.

Shrivastava, P. (1994). CASTRATED Environment: GREENING Organizational Studies. *Organization Studies*, *15*(5), 705–726. https://doi.org/10.1177/017084069401500504

Shrivastava, P. (1995a). Ecocentric management for a risk society. *Academy of Management Review*, *20*(1), 118–137.

Shrivastava, P. (1995b). The Role of Corporations in Achieving Ecological Sustainability. *Academy of Management Review*, *20*(4), 936–960. https://doi.org/10.5465/amr.1995.9512280026

Shrivastava, P., Ivanaj, S., & Persson, S. (2013). Transdisciplinary Study of Sustainable Enterprise. *Business Strategy and the Environment*, *22*(4), 230–244. https://doi.org/10.1002/bse.1773

Shrivastava, P., & Kennelly, J. J. (2013). Sustainability and Place-Based Enterprise. *Organization & Environment*, *26*(1), 83–101. https://doi.org/10.1177/1086026612475068

Slawinski, N., Pinkse, J., Busch, T., & Banerjee, S. B. (2017). The Role of Short-Termism and Uncertainty Avoidance in Organizational Inaction on Climate Change: A Multi-Level Framework. *Business and Society*, *56*(2), 253–282. https://doi.org/10.1177/0007650315576136

Smith, W. K., & Lewis, M. W. (2011). Toward a theory of paradox: A dynamic equilibrium model of organizing. *Academy of Management Review*, *36*(2), 381–403. https://doi.org/10.5465/AMR.2011.59330958

Smith, W. K., & Tushman, M. L. (2005). Managing Strategic Contradictions: A Top Management Model for Managing Innovation Streams. *Organization Science*, *16*(5), 522–536. https://doi.org/10.1287/orsc.1050.0134

Sonnemann, G., Gemechu, E. D., Sala, S., Schau, E. M., Allacker, K., Pant, R., … Valdivia, S. (2018). Life Cycle Thinking and the Use of LCA in Policies Around the World. In *Life Cycle Assessment* (pp. 429–463). https://doi.org/10.1007/978-3-319-56475-3_18

Starik, M. (2013). Organization & Environment. *Organization & Environment*, *26*(3), 239–240. https://doi.org/10.1177/1086026613499233

Starik, M., & Kanashiro, P. (2013). Toward a Theory of Sustainability Management. *Organization & Environment*, *26*(1), 7–30. https://doi.org/10.1177/1086026612474958

Starik, M., & Marcus, A. A. (2000). Introduction to the special research forum on the management of organizations in the natural environment: A field emerging from multiple paths, with many challenges ahead. *Academy of Management Journal*, *43*(4), 539–546.

Starik, M., & Rands, G. P. (1995). Weaving an Integrated Web: Multilevel and Multisystem Perspectives of Ecologically Sustainable Organizations Definitions and Desirability of Ecological Sustainability. ® *Academy Oi Management Review*, *20*(4), 908–935.

Steffen, W., Richardson, K., Rockstrom, J., Cornell, S. E., Fetzer, I., Bennett, E. M., … Sorlin, S. (2015). Planetary boundaries: Guiding human development on a changing planet. *Science*, *347*(6223), 1259855–1259855. https://doi.org/10.1126/science.1259855

Tokede, O., & Traverso, M. (2020). Implementing the guidelines for social life cycle assessment: past, present, and future. *The International Journal of Life Cycle Assessment*, *25*(10), 1910–1929. https://doi.org/10.1007/s11367-020-01814-9

UNEP. (2012). *Greening the Economy Through Life Cycle Thinking. Ten Years of the UNEP/SETAC Life Cycle Initiative*. Retrieved from https://www.lifecycleinitiative.org/wp-content/uploads/2013/03/2012_LCI_10_years_28.3.13.pdf

United Nations. (2015). *Transforming our World: The 2030 Agenda for Sustainable Development. A/RES/70/1*. Retrieved from https://sustainabledevelopment.un.org/content/documents/21252030 Agenda for Sustainable Development web.pdf

Van der Byl, C. A., & Slawinski, N. (2015). Embracing Tensions in Corporate Sustainability. *Organization & Environment*, *28*(1), 54–79. https://doi.org/10.1177/1086026615575047

Welford, R. J. (1998). Editorial: Corporate environmental management, technology and sustainable development: postmodern perspectives and the need for a critical research agenda. *Business Strategy and the Environment*, *7*(1), 1–12. https://doi.org/10.1002/(SICI)1099-0836(199802)7:1<1::AID-BSE132>3.0.CO;2-7

Whiteman, G., Walker, B., & Perego, P. (2013). Planetary Boundaries: Ecological Foundations for Corporate Sustainability. *Journal of Management Studies*, *50*(2), 307–336. https://doi.org/10.1111/j.1467-6486.2012.01073.x

Wickson, F., Carew, A. ., & Russell, A. W. (2006). Transdisciplinary research: characteristics, quandaries and quality. *Futures*, *38*(9), 1046–1059. https://doi.org/10.1016/j.futures.2006.02.011

Wiesmann, U., Biber-Klemm, S., Grossenbacher-Mansuy, W., Hadorn, G. H., Hoffmann-Riem, H., Joye, D., … Zemp, E. (2008). Enhancing Transdisciplinary Research: A Synthesis in Fifteen Propositions. In G. Hirsch Hadorn, H. Hoffmann-Riem, S. Biber-Klemm, W. Grossenbacher-Mansuy, D. Joye, C. Pohl, & E. Zemp (Eds.), *Handbook of Transdisciplinary Research* (pp. 433–441). https://doi.org/10.1007/978-1-4020-6699-3_29

Williams, A., Kennedy, S., Philipp, F., & Whiteman, G. (2017). Systems thinking: A review of sustainability management research. *Journal of Cleaner Production*, *148*, 866–881. https://doi.org/10.1016/j.jclepro.2017.02.002

Williamson, O. E. (Ed.). (1990). *Organization theory: From Chertern Barnard to the present and beyond*. New York: Oxford University Press.

Winn, M. I., & Pogutz, S. (2013). Business, Ecosystems, and Biodiversity. *Organization & Environment*, *26*(2), 203–229. https://doi.org/10.1177/1086026613490173

WMO. (2020). *United in Science 2020. A multi-organization high-level compilation of the latest climate science information*. Retrieved from https://public.wmo.int/en/resources/united_in_science

Wulf, C., Zapp, P., Schreiber, A., Marx, J., & Schlör, H. (2017). Lessons Learned from a Life Cycle Sustainability Assessment of Rare Earth Permanent Magnets. *Journal of Industrial Ecology*, *21*(6), 1578–1590. https://doi.org/10.1111/jiec.12575

Yin, R. K. (1994). *Case study research. Design and methods. Second edition* (Applied So). Thousand Oaks: Sage Publications Inc.

Zamagni, A., Pesonen, H.-L., & Swarr, T. (2013). From LCA to Life Cycle Sustainability Assessment: concept, practice and future directions. *The International Journal of Life Cycle Assessment*, *18*(9), 1637–1641. https://doi.org/10.1007/s11367-013-0648-3

UNIVERSITY OF TURKU

ISBN 978-951-29-8346-9 (PRINT)
ISBN 978-951-29-8347-6 (PDF)
ISSN 2343-3159 (Print)
ISSN 2343-3167 (Online)

Painosalama Oy, Turku, Finland 2021