ENVIRONMENTAL ASSEMENT OF GHG EMISSON IMPACTS

- a study of current practice and potentials for including life cycle thinking

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Abstract:

Recent research has emphasised that there is a need for more systematic and thorough assessments of greenhouse gas (GHG) emissions in environmental assessments. Therefore, this thesis aims to explore potentials for improving the Danish practice of assessing GHG emissions in environmental assessments by applying life cycle thinking (LCT). Firstly, this entails looking at how GHG emissions are assessed i current Danish EA practice. A text analysis of 102 EA reports revealed that several shortcomings exist in this regard, including a prevalent use of insufficient references in determining significance, and a lack of inclusion of life cycle phases. Due to its capabilities, e.g. systems perspectives, hotspot analysis, and so on, this thesis supports application of LCT and Life cycle assessment (LCA). Based on a survey with EA practitioners, it can be deduced that the knowledge and experience regarding LCA application may be a challenge. This is also apparent from existing EA reports, as very few include LCT in the assessments. In order to demonstrate how the assessment of GHG emissions can benefit from LCT, the approach is applied to two existing EIA reports. Based on the results of this experiment, LCT can contribute with a systems perspective thereby reducing the risk of overlooking relevant activities in the assessment. Furthermore, it can contribute to more well-founded assessments, thus supporting more accurate significance determinations. However, it is clear that LCT is not a stand-alone solution to improving significance determination, and therefore it is recommended that threshold values for GHG emissions should be established. Finally, the thesis includes a discussion which seeks to explore the institutional setting of GHG emission assessment practice. It is concluded that elements within the pillars contribute to both restraining current practice, and to driving practice forward.

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Preface

The authors of this thesis are three students from the fourth and final semester of the master's programme *Environmental Management and Sustainability Science* at Aalborg University. The thesis is carried out from February 2nd of to June 3rd, 2022.

The aim of the master's thesis is to examine how GHG emission impacts is assessed in Danish environmental assessments (EA) and how life cycle thinking (LCT) can contribute to improving these assessments. Therefore, the results of the thesis are relevant for researchers, practitioners, developers, and other stakeholders within these disciplines, who are interested in the potentials of LCT application for EA purposes.

The authors would like to express their gratitude to the following interviewees for contributing with relevant knowledge:

- Anna Björklund, Chemical Engineer and Professor in Environmental Strategic Research
- Bo Weidema, Professor at Aalborg University at The Danish Centre for Environmental Assessment (specialised in LCA)
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Reading guide
It is recommended that this thesis is read in chronological order. In chapter 3, a visualisation of the thesis' structure, research questions, and methodologies are provided to guide the reader.

As a reference system, the Harvard referencing style is applied. References appear in-text as "[author's surname, year]". Citations contain the author(s)'s surname, year of publication and page number(s), and is written in italics. To give the reader a better understanding of the quotations, words or sentence are sometimes added in brackets followed by ed. (edited): "[xx, ed.]".

The thesis contains two bibliographies: one for references and one for EIA and SEA reports cited in the thesis. Citations from the EA reports are referenced as "(EIA/SEA: title, author(s), year, page number(s))".

The separate attached annex contains excel sheets including background data for the thesis' analyses.

Summary

Klimaets tilstand betragtes som kritisk, og drivhusgasemissioner, som følge af menneskelige aktiviteter, har utvetydigt medført klimaforandringer overalt på jorden. Jævnfør den danske klimalov af 2020, skal det danske samfund opnå klimaneutralitet inden 2050, mens de samlede nationale udledninger af drivhusgasser skal reduceres med 70% inden 2030. Med henblik på at opnå disse mål, er det essentielt, at klimapåvirkninger adresseres på alle niveauer af planlægning.

På baggrund af det ovenstående tager dette speciale udgangspunkt i den formelle procedure for miljøvurdering af planer, programmer og af konkrete projekter, nærmere bestemt vurderingen af disses bidrag til klimaforandringer gennem drivhusgasemissioner. Miljøvurderingsprocessens formål er at sikre et højt niveau af miljøbeskyttelse, herunder at fremme bæredygtig udvikling og sikre, at offentligheden inddrages så tidligt som muligt, og forud for at der træffes afgørelse om den pågældende plan, program, eller projekt. Gennem forudsigelse og vurdering af de forventede væsentlige miljøpåvirkninger, fungerer processen således som et beslutningsstøttende værktøj.

Adskillige interessenter fremhæver miljøvurderingens potentialer i henhold til vurderingen af planer, programmer og projekters indvirkninger på klimaforandringer. Resultater af forskning og evalueringer viser dog, at miljøvurderingen i praksis er utilstrækkelig på flere områder, når klimapåvirkninger skal adresseres. Dette omfatter blandt andet manglen på tilstrækkelige metoder, værktøjer og data, hvilket bidrager til et for lavt detaljeringsniveau. Ydermere har forfatterne bag dette speciale gennem tidligere forskning konkluderet, at vurderinger af projekters klimapåvirkninger sjældent inddrager alle livscyklusfaser og betragtninger om globale eller kumulative virkninger.

Specialets formål er at bidrage til den eksisterende viden ved at undersøge potentialerne for anvendelse af livscyklustænkning (LCT) i vurderingen af klimapåvirkninger fra planer, programmer og projekter. LCT er en tilgang, som understøtter forståelsen for miljørelaterede problematikker af produkter, systemer og aktiviteter i et livscyklusperspektiv. I praksis operationaliseres konceptet gennem livscyklusvurdering (LCA), som er et værktøj, der anvendes til at estimere miljøpåvirkningerne fra et produktsystem. Det antages på denne baggrund, at LCT (og LCA) kan komplementere den lovpligtige miljøvurderingsprocedure som en konkret metode til at estimere klimapåvirkninger i et livscyklusperspektiv. Heraf udspringer problemformuleringen:

> *Hvordan kan livscyklustænkning bidrage til at forbedre vurderinger af påvirkninger af drivhusgasemissioner i miljøvurdering?*

Problemformuleringen besvares gennem tre underspørgsmål, som danner retning for forskningen.

Det første spørgsmål har til hensigt at undersøge den nuværende danske miljøvurderingspraksis for vurdering af påvirkninger fra drivhusgasemissioner, hvortil der anvendes forskellige metoder. Ud fra en spørgeskemaundersøgelse, med i alt 60 miljøvurderingspraktikere som respondenter, konkluderes det, at respondenterne generelt har et negativt syn på kvaliteten af vurderingerne og de metoder, som anvendes. Ydermere oplever praktikerne et pres for, at vurderingerne forbedres. Hertil anvendes tekstanalyse af 51 miljøkonsekvensrapporter og 51 miljørapporter, udgivet i årene 2020 og 2021, som metode til at undersøge den nuværende praksis. Det konkluderes, at vurderingerne generelt inddrager få livscyklusfaser (ofte kun én - driftsfasen), samt at der er mangel på transparens og systematik i vurderinger af påvirkningernes væsentlighed. Påvirkninger, i form af drivhusgasemissioner, vurderes overvejende at være uvæsentlige eller små, mens de som vurderes at være væsentlige, næsten udelukkende er positive påvirkninger. Ydermere anvendes adskillige forskellige referencer som sammenligningsgrundlag for vurderingen af drivhusgasemissioners væsentlighed, som overordnet betragtes som tilstrækkelige.

Formålet med det andet undersøgelsesspørgsmål er at identificere fordele og begrænsninger ved at anvende LCT i miljøvurderingssammenhæng samt at afdække omfanget af den nuværende anvendelse af LCA i denne sammenhæng. På baggrund af et semistruktureret litteraturreview, hvori 16 relevante artikler identificeres, og perspektiver fra interviews med fire forskere, kan det konkluderes, at bidraget fra LCT omfatter evnen til at identificere miljømæssige hotspots (de mest væsentlige aktiviteter af livscyklusfaser), samt at sammenligne alternativer kvantitativt. Af udfordringer fremhæves ressourcebehovet, som især LCA-beregninger medfører, samt manglen på kompetencer blandt praktikere. I henhold til praksis for anvendelse af LCA viser resultaterne fra den føromtalte spørgeskemaundersøgelse også, at der blandt praktikere er mangel på viden og kompetencer. Respondenterne mener dog overvejende, at vurdering af påvirkninger fra drivhusgasemissioner bør være mere datadreven, men oplever dog ikke pres eller efterspørgsel på at integrere LCA i vurderingspraksis. For at undersøge praksis for anvendelsen af LCA til vurdering af drivhusgasemissioner anvendes tekstanalyse af 276 rapporter udgivet i perioden 2017-2021. Det konkluderes, at LCA sjældent anvendes, da få rapporter referer til tidligere LCA-studier, mens blot en håndfuld har anvendt værktøjet aktivt. Fælles for disse er, at afviklingsfasen konsekvent ekskluderes uden retfærdiggørelse, og alt i alt indikerer resultaterne, at LCA ikke er en integreret del af den eksisterende praksis.

Med udgangspunkt i de foregående analysers konklusioner har det tredje og sidste spørgsmål til formål at demonstrere, hvordan LCT kan anvendes til vurdering af påvirkninger fra drivhusgasemissioner. I denne sammenhæng udvælges to miljøkonsekvensrapporter, der anvendes som cases til at eksemplificere, hvordan LCT kan anvendes. Resultaterne viser, at begge vurderinger af projekternes drivhusgasemissioner er baseret på en meget begrænset del af projekternes livscyklus. Hertil udføres LCA screeninger af begge projekter, for at kunne identificere hvilke livscyklusfaser og aktiviteter, der fører til de mest betydelige påvirkninger. Resultaterne heraf viser, at de mest signifikante aspekter ikke er inkluderet i vurderingerne. Anvendelsen af LCT understreger altså, at stillingtagen til alle aktiviteter og faser er afgørende for at sikre, at potentielt væsentlige bidrag til drivhusgasemissioner undersøges og håndteres.

Hvad angår væsentlighedsvurdering, argumenteres der for, at LCT bidrager til at skabe et mere solidt vurderingsgrundlag, mens hotspot-analyse kan være retningsgivende for vurderinger. Endvidere muliggør den funktionelle enhed, som anvendes til at skalere resultater, sammenligning af både alternativer og hele produktsystemer. Det konkluderes dog, at LCT ikke er en enkeltstående løsning, da referencer er nødvendige som sammenligningsgrundlag i vurderingen af væsentlighed. Derfor foreslås det, at grænseværdier for drivhusgasemissioner implementeres, som er i overensstemmelse med danske klimamål, og som er specifikke for de individuelle plan-, program- og projekttyper.

Den overordnede konklusion på dette speciales problemformulering er altså:

- LCT bidrager til at opnå en mere omfattende forståelse for systemer, hvilket reducerer risikoen for at overse potentielt væsentlige aktiviteter i et livscyklusperspektiv.
- Hotspot-analyse er en effektiv måde at identificere de mest betydelige livscyklusfaser og aktiviteter på, hvilket anses som et værdifuldt bidrag til miljøvurderingens screening- og afgrænsningsfaser.
- Overordnet bidrager LCA til et mere solidt vurderingsgrundlag, hvilket understøtter mere eksakte væsentlighedsvurderinger.
- Da LCT ikke anses som en selvstændig løsning foreslås implementering af grænseværdier for drivhusgasemissioner for at tilvejebringe et tilstrækkeligt sammenligningsgrundlag for vurderingen af væsentlighed.

Udover besvarelse af problemformuleringen omfatter specialet også et blik på den nuværende praksis for vurderingen af drivhusgasemissioner, baseret på teorien af om de tre institutionelle søjler. Formålet er at skabe en forståelse for, hvilken retning udviklingen går. Overordnet konkluderes det, at elementer indenfor hver af de institutionelle rammer bidrager til dels at fastholde den nuværende praksis og dels at drive udviklingen fremad. Indenfor den regulerende søjle bidrager manglen på grænseværdier og myndigheders ageren til at fastholde praksis, mens vejledninger og strengere krav potentielt kan drive udviklingen. De fastholdende normative elementer omfatter "business as usual"-tilgangen og anvendelsen af utilstrækkelige sammenligningsgrundlag i væsentlighedsvurderinger, mens drivkræfterne omfatter den øgede opmærksomhed på klimaforandringer og offentlighedens forventninger. Den kognitive-kulturelle søjle omfatter misforståelser om klimaforandringer, som fastholder praksis, og forskningsresultater som drivkræft for udviklingen. Overordnet betragtes praksis som værende i udvikling mod mere retvisende vurderinger af drivhusgasemissioner.

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List of Abbreviations

Abbreviation	Meaning
EA	Environmental Assessment
EIA	Environmental Impact Assessment
EU	European Union
FU	Functional unit
GHG	Greenhouse gas
IA	Impact Assessment
ISO	International Organization of Standardization
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
LCT	Life Cycle Thinking
PPP	Plan, programme, and project
SEA	Strategic Environmental Assessment

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1 Introduction

In 2021 the Intergovernmental Panel on Climate Change (IPCC) published their 6th. assessment report, containing the most up-to-date knowledge of the state of climate change [IPCC, 2021]. The report concluded that human induced greenhouse gas (GHG) emissions have unequivocally caused climate changes in every region of the globe, with anticipated global surface temperature rises of 1.5°C and 2°C. Furthermore, it expected that these rises will have been exceeded by the end of this century, unless radical reductions of GHG emissions occur. Thus, the climate situation is considered critical, and many countries have implemented national as well as international climate goals in order to ensure reductions in GHG emissions. In a Danish context, a proactive climate act has been implemented, containing the ambitious national goal of achieving a 70% reduction of GHG emissions by 2030 (compared to 1990), and the overall objective of becoming climate neutral within 2050 [The Danish Ministry of Climate, Energy and Utilities, 2020]. However, based on current political initiatives, it is anticipated that Denmark will only have reached a 57% reduction of GHG emissions by 2030 [Danish Energy Agency, 2022], indicating that action is needed. As an extra dimension, the fulfilment of the goals needs to happen in a cost effective way, without compromising the development within the Danish businesses sector or its competitiveness. In order to comply with the goals, it is therefore important that GHG emissions are addressed at all levels of planning.

The traditional and institutionalised approach to addressing the environmental impacts induced by plans, programmes, and projects (PPPs) is environmental assessment (EA)[1]. These are mandatory procedures for PPPs which are expected to cause significant negative environmental impacts. The EU directives 2011/92/EU (later amended by Directive 2014/52/EU) and 2001/42/EC regulate EA procedures [The European Union, 2011, 2014]. Based on this, Denmark has implemented the "Declaration of the Law on Environmental Assessment of Plans and Programs and of Specific Projects" which sets legal requirements for EA processes. The overall goal is to ensure a high level of environmental protection, and to promote sustainable development. Furthermore, the purpose of the law is also to ensure that the public is included as early as possible, and prior to decision making [The Danish Ministry of Environment, 2021]. The EA procedure supports decision making by anticipating and assessing the environmental consequences of proposed PPPs, and presenting relevant measures to mitigate significant impacts [Kørnøv et al., 2015].

Overall, multiple organisations have emphasised that EA possesses great potential for assessing the climatic impacts of PPPs [IEMA, 2022; IAIA, 2018; The European Union, 2013a,b]. It can contribute to assisting governments in meeting climate targets, informing relevant stakeholders and the general public about the negative climate effects of PPPs,

[1] In this thesis, EA is used as a term that covers both EIA for appraisal of projects and SEA for appraisal of plans and programmes.

and identifying and accommodating potential synergies between climate and other environmental impacts. Despite of this, an evaluation of the SEA directive showed that stakeholders perceived the directive as "less effective" in addressing climatic factors. The identified challenges include limited methods, tools, and data [The European Commission, 2019]. Furthermore, scientific publications have concluded that assessments of GHG emissions often have a low level of detail, which affects the quality of EIA reports [Larsen, 2014; Larsen and Rasmussen, 2014; Underwood et al., 2021]. These findings are comparable to previous studies conducted by the authors of this thesis, focusing on assessment of GHG emissions in Danish EIA practice [Munk, 2022; Christensen, 2022]. These studies demonstrated that assessments often failed to include all project life cycle phases as well as considerations of the impact in a global cumulative context. In other words, the assessments were perceived as inaccurate which affected the determination of significance. Moreover, the determination of GHG impact significance had no systematic approach, and GHG emission impacts were often compared to annual national emissions. In order to accommodate these obstacles and improve the practise, it is suggested by both Munk [2022] and Christensen [2022] that greater consideration of life cycle phases could be beneficial. This thesis seeks to build upon these findings.

Life cycle thinking (LCT) is an approach to understanding the environmental issues related to products, systems or activities over the entirety of their life cycles. Based on the concept of systems thinking, LCT is a means of structuring life cycles, which contributes to keeping track of environmental performance [Thrane and Schmidt, 2007b]. In scientific literature, the benefits of LCT have mainly been demonstrated in form of life cycle assessment (LCA) [Larrey-Lassalle et al., 2017; Madhu and Pauliuk, 2019; Björklund, 2012; Manuilova et al., 2009; Rybaczewska-Blażejowska and Palekhov, 2018; Tukker, 2000]. Compared to other environmental assessment tools, the most significant characteristic of LCA, is the ability to present potential impacts in a life cycle thinking [Thrane and Schmidt, 2007a]. This means that impacts appertaining to all life cycle stages including raw material extraction, processing, distribution, use, and disposal are taken into account. Therefore, it can be argued that LCT (and LCA) provide an opportunity to complement various aspects of EA procedures. While EA and LCT have their individual strengths and weaknesses, potentials exist in regards to e.g. the scoping phase of EA, where LCA can contribute to identifying key impacts, and to comparing alternatives quantitatively [Larrey-Lassalle et al., 2017]. EA is a legal requirement, which ensures that a holistic approach to assessing the impacts of proposed PPPs. As presented, however, the procedure lacks methods, tools, data, and a sufficient level of detail in assessing GHG emissions. It could also be argued that climatic factors challenges the traditional focus of EA, as impacts are not confined to a specific geography. LCT on the other hand makes no distinction in this regard, and accounts for both up- and downstream life cycle processes [Larrey-Lassalle et al., 2017]. For these reasons, LCT is perceived as an ideal counterpart, providing a methodological approach and ensuring that relevant life cycle phases are accounted for.

Based on these acknowledgements, this thesis sets out to answer the following research question:

How can life cycle thinking contribute to improving assessments of GHG emission impacts in environmental assessment?

For reasons of practicality (i.e. access to EA reports, survey respondents and interviewees) the research is based on Danish EA practice.

The thesis contains a total of nine chapters, the first of which is this introduction. The second chapter describes the basic relations between EA and GHG emission impacts, culminating in a presentation of the research question and related sub-questions. Chapter three concerns the research design, including structure, methods and theory. The research is initiated in chapter four, in which the current Danish practice of GHG emissions assessment is explored. Chapter five presents existing research on LCT in an EA context, and the practice of LCA application in EA. Consequently, chapter six sets out to demonstrate how LCT can be applied in an actual EA context, thus answering the research question. Focus then shifts to an institutional view upon the practice in chapter seven, before concluding the thesis in chapter eight, and presenting final perspectives in chapter nine.

2 Environmental assessment and GHG emission impacts

The purpose of this chapter is to present the relation between GHG emission impacts and EA processes, in order to gain an understanding of the potential issues and focus areas for the coming analysis. Initially, an overview of entry points for climate change considerations throughout the EA procedure is presented. This is done in order to specify when considerations are relevant, and how relevant climate change aspects can be accounted for. Subsequently, the legislative requirements for assessing GHG emissions in EA are summarised. Then follows a review of relevant guidance documents, focusing on what the documents highlight as important when assessing GHG emissions in EAs. This aims to present the best practice guidance from governments and other relevant stakeholders. Lastly, findings of existing research on assessment of GHG emissions in Danish EAs is described, including a presentation of previous studies conducted by the authors.

2.1 EA legislation

The objective of EA is to anticipate the environmental impacts of a proposed PPP and its alternatives, before deciding upon whether or not to implement the PPP [The Danish Ministry of Environment, 2021]. In other words, the overall objective is to provide a solid foundation for decision making that accounts for relevant environmental concerns. EA procedures ensure a broad environmental focus where social, economical, and environmental considerations are assessed on equal terms [Kørnøv et al., 2015]. Due to this holistic approach, EA has the ability to link different environmental impacts instead of assessing them individually. In the context of GHG emission impacts, this is highly relevant since increased GHG emissions have an impact on many environmental parameters including loss of biodiversity, human well-being etc. [The European Union, 2013a,b; IAIA, 2018]. As a result, the importance of including climatic factors in EAs is generally recognised by international and national declarations. For example, the EU DIRECTIVE 2014/52/EU specifies:

Directive 2011/92/EU as amended by Directive 2014/52/EU
(13) Climate change will continue to cause damage to the environment and compromise economic development. In this regard, it is appropriate to assess the impact of projects on climate (for example greenhouse gas emissions) and their vulnerability to climate change.

Table 2.1. [The European Union, 2014, p.3]

As a result, climate change impacts from PPPs are legally required to be assessed in EIA and SEA cf. both international and national declarations [The European Union, 2011, 2001; The Danish Ministry of Environment, 2021]. In Denmark, this is specified in § 1 pcs. 2 of the Danish "Declaration of the Law on Environmental Assessment of Plans and Programmes and of Specific Projects". It is stated that environmental impacts, (including climatic impacts) must be assessed if they are deemed potentially significant. For SEA, climatic impacts are mentioned among many other environmental parameters that need to be assessed cf. Annex 4, f), while climatic impacts are mentioned separately in Annex 7, point 5. f) regarding the contents of the EIA report:

Declaration of the Law on Environmental Assessment of Plans and Programmes and of Specific Projects
Annex 7, point 5 (f) A description of the likely significant effects of the project on the environment resulting from, inter alia: (f) the impact of the project on climate (for example the nature and magnitude of greenhouse gas emissions) and the vulnerability of the project to climate change;

Table 2.2. [The Danish Ministry of Environment, 2021,Annex 7, point 5 (f)]

In relation to analysing and assessing climatic impacts, the Danish EA legislation sets few requirements. For EIA, it is required that likely significant environmental impacts (including climatic impacts) are described in relation to the construction and existence of the project, and where relevant demolition activities cf. Annex 7, point 5 a) [The Danish Ministry of Environment, 2021]. In addition, the cumulation of effects with other existing and/or approved projects should also be described cf. Annex 7, point 5 e). Besides these requirements, the Danish EA legislation does not specify how climatic impacts are to be assessed, e.g. in relation to choice of method or criteria for determining significance.

2.2 The EA procedure

Today, EIA procedures for projects are mandatory in most countries, and many have also adopted SEA procedures for plans and programmes [Mayer, 2018]. Because of this, it is recognised that EA holds potential as a tool for accommodating large-scale global environmental impacts such as climate change [IAIA, 2018; IEMA, 2022; Larsen, 2014]. Figure 2.1 presents a generalised overview of how climate change considerations can be integrated through the different steps of the EA procedure. In reality, the process is not linear, and steps may occur both simultaneously, and in a different order.

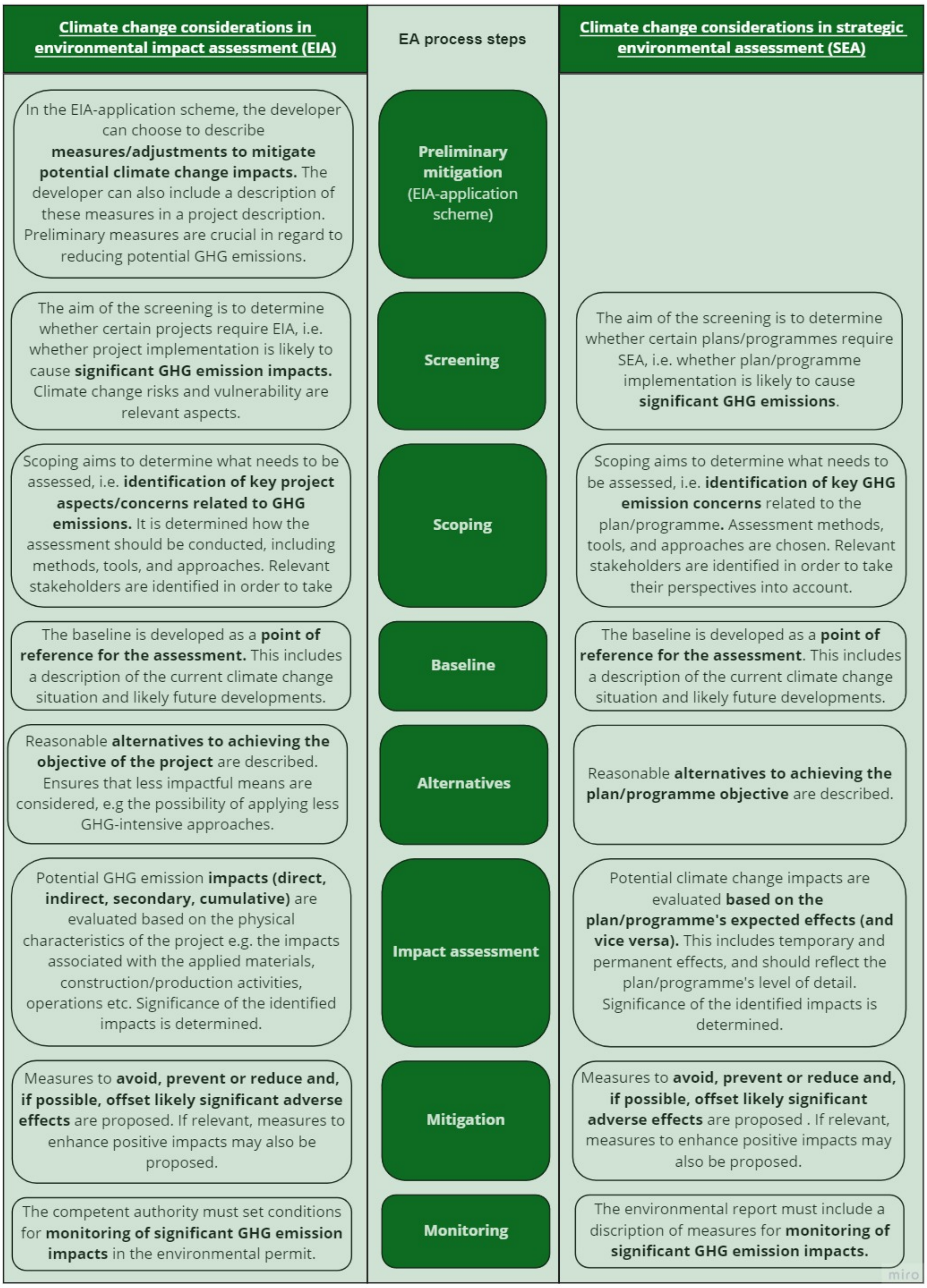


Figure 2.1. Overview of how climate change considerations can be integrated through the different steps of the EA procedure. The figure includes both EIA and SEA, as some variations between the procedures exist. Based on legislative- and guidance documents [IEMA, 2022; The European Union, 2013a,b; The Danish Environmental Protection Agency, 2022a,b; The Danish Ministry of Environment, 2021; The Danish Environmental Protection Agency, 2021; Agrawala et al., 2010].

Preliminary mitigation
As is exemplified by the figure, preliminary mitigation is the first step of which climate change considerations can be integrated in the EIA process. As stated in the Danish Consolidation Act on environmental assessment (annex, point 42), the developer's project application may include a description of any features of the project prior to submitting the application and/or measures envisaged to avoid, prevent, reduce or offset significant adverse effects on the environment [The Danish Environmental Protection Agency, 2021]. This promotes consideration of measures to mitigate GHG emission impacts early on. According to both The European Union [2013a] and IEMA [2022], early mitigation is a key aspect in terms of reducing GHG emissions and can be achieved through initiatives such as energy efficiency-, technology- and/or process improvements.

Screening
Screening is usually the first "formal" step of an EA process (for projects listed in Annex II and for plans and programmes subject to §8 of the Danish law on environmental assessment) as its purpose is to determine whether or not the proposed PPP requires an EA [The Danish Ministry of Environment, 2021]. For specific PPP types (listed in Annex 1), EA is mandatory, meaning that the assessment initiates with the scoping step. In relation to climate change, screening phases of both EIA and SEA processes aims at determining whether the proposed PPP are likely to cause significant climate change impacts [The European Union, 2013a,b]. Several aspect are required to be considered (for plans and programmes cf. annex 3) such as the magnitude, spatial extent, probability, and duration of impacts. Furthermore, considerations related to project sensitivity and/or vulnerability to climate change are required (cf. annex 6, point 2) [The Danish Ministry of Environment, 2021]. Due to the nature of GHG emissions, i.e. the fact that they are not geographically limited, all activities that induce GHG emissions contribute cumulatively and globally to climate change. This means that climate change has a high level of sensitivity to all contributing factors, which should be taken into account when determining the likely significance of impacts [IEMA, 2022].

Scoping
The scoping step aims at determining what should be assessed. This includes identification of key aspects of the PPP related to climate change. In relation to EIA, key aspects must include both direct emissions (e.g. construction, operations, land use) and indirect emissions (e.g. increased energy demand, supporting activities, and infrastructure) induced by the project [The European Union, 2013a]. For SEA, relevant aspects include the proposed plan or programme's influence on energy demand, GHG emissions related to agriculture, waste management, etc. [The European Union, 2013b]. Another aspect of the scoping phase is how the assessment is to be conducted, i.e. the selection of methods, tools, and approaches. The relevance of these will depend on the specific context of the proposed PPP, while the level of detail will also depend on the information available. Specifically for SEA, the Danish law on EA states that the environmental report must contain information corresponding to existing knowledge and level of detail of the proposed plan or programme [The Danish Ministry of Environment, 2021]. Furthermore, scoping phase also concerns the consultation of the public and key stakeholders, who can contribute to identifying relevant climate change issues [The European Union, 2013a,b].

Baseline and alternatives

As part of the assessment of GHG emission impacts a baseline must be established. This serves as a point of reference for the assessment, and should include a description of the environmental characteristics, i.e. the current climate change situation, as well as a projecting future developments [Agrawala et al., 2010; The European Union, 2013a; IEMA, 2022]. In order to account for uncertainties, it may be necessary to present and assess several future baseline scenarios, as these may influence the potential impacts of the proposed PPP [IEMA, 2022]. For example, different scenarios for future energy supply may influence the GHG intensity of e.g. a production facility. Additionally to establishing the baseline, relevant alternatives are identified. The role of these is to support the decision making process by presenting alternative means to achieving the objective of the proposed PPP [Kørnøv et al., 2015]. In the context of EIA, alternatives concern how to handle key climate change issues, e.g. choosing less GHG intensive construction methods, altering project design, adopting alternative technologies, or considering different locations [The European Union, 2013a]. However, for GHG emission impacts, alternatives are best considered at the strategic level (SEA), as key issues can be addressed early on in the planning process. According to the EU guidance on integrating climate change and biodiversity in SEA, *"Considering alternatives should encourage the planning process to look for better ways to meet human needs without contributing to climate change"* [The European Union, 2013b,p. 42]. Thus, considering alternatives in SEA provides an opportunity to integrate climate change considerations at the planning level.

Impact assessment

Several approaches to the assessment of GHG emissions exist. The impact of projects (EIA) is assessed based on the physical characteristics, e.g. the applied materials, construction/production activities, and impacts during the operational phase [Kørnøv et al., 2015]. A multitude of tools may be applied, including carbon footprint exercise, GHG conversion factors and emission calculators, life cycle assessment, etc. [The European Union, 2013a]. GHG emissions impacts are complex due to the long-term, global and cumulative nature of the effects The European Union [2013a], which makes determining significance a difficult task. As such, it is important to establish and apply significance criteria. As an example, IEMA [2022] recommend that significance determination is based on the project's compliance with the UK's net zero trajectory i.e. that GHG emission impacts are considered major adverse (significant) if they do not make a meaningful contribution to the UK's trajectory towards net zero.

Mitigation

As stated previously, preliminary efforts are essential in mitigating GHG emissions from PPPs, as eliminating (avoiding) GHG emissions is more favourable than mitigating the impacts. In this regard, mitigation measures for climate change have the largest potential at the strategic level (SEA) [The European Union, 2013a,b]. For projects (EIA), measures may taken to mitigate direct impacts, e.g. through technical adjustments, protection of carbon sinks or GHG off-setting, as well as indirect impacts from e.g. project induced energy consumption or transport [The European Union, 2013a].

Monitoring

The goal of monitoring measures is to "verify" impact predictions, as well as identifying potentially overlooked impacts [The European Union, 2013a]. For complex issues such as climate change, identifying relevant monitoring indicators is key. For projects (EIA), the competent authority sets conditions for monitoring of significant impacts of GHG emissions, while it is required that SEA reports include a description of monitoring of significant impacts [The Danish Ministry of Environment, 2021].

2.3 Guidance documents

The purpose of this section is to present relevant guidance documents and elaborate on what they perceive as important when assessing GHG emissions in EAs.

Several guidance documents from governmental and non-governmental organisations have been prepared with the purpose of contributing with perspectives and guidance for improving the assessments of GHG emissions in EA. Figure 2.2 presents an overview of some of the governmental guidance documents related to environmental assessments arranged according to different levels of decision-making.

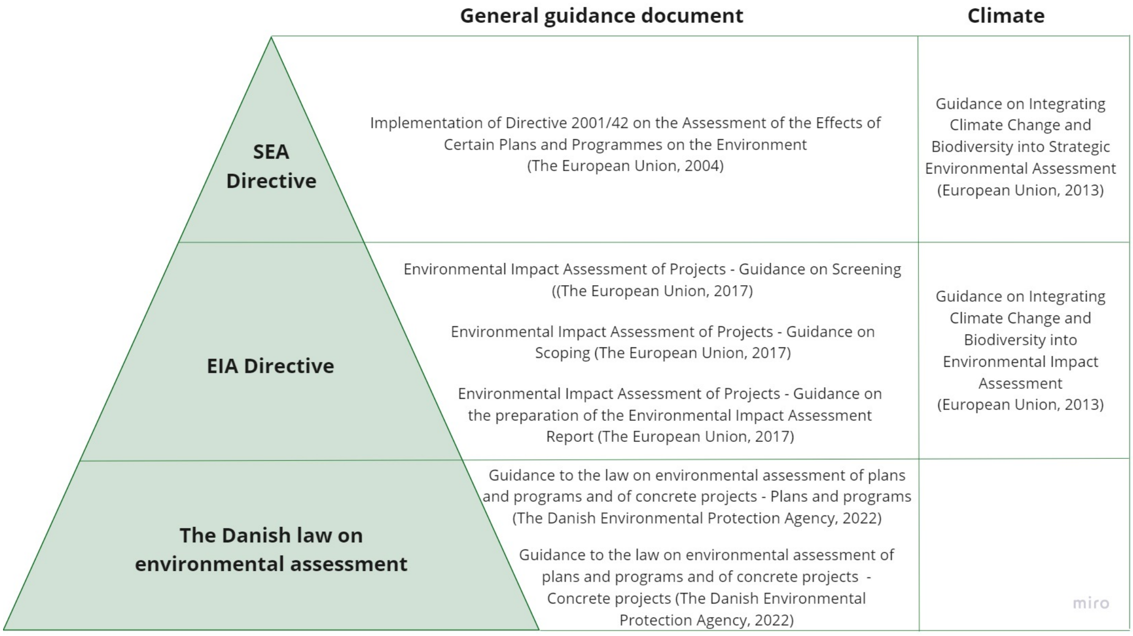


Figure 2.2. Overview of general guidance documents related to environmental assessment at various strategic levels, and guidance documents specifically aimed at the assessment of climate as an environmental factor.

Generally, the intention of the guidance documents related to the directives is to ensure:

> *"(...) that Member States have a clear understanding of the Directive's requirements, so that it is implemented consistently throughout the EU. "* [The European Union, 2004,p. 1]

The guidance documents related to the Danish law on environmental assessment have a similar aim as they are legal documents based on the law, directives, and EU guidance documents. The guidelines for properly addressing GHG emissions in EA have been compiled from several of these guidance documents, as well as from non-governmental organisations regarding the topics: describing baseline, the use of environmental targets, assessment of GHG emissions, determining mitigation measures, determining impact significance, and describing uncertainties. The aim is to figure out what is considered good practice in terms of GHG emission assessments. However, it is noteworthy that guidance documents present some sort of interpretation of the law, which can differ and change over time.

The findings are presented in tables 2.3 and 2.4, which respectively concern the guidance related to EIA and SEA. Based on the findings presented in these tables, the identified guidance documents are generally aligned in their guidance for the listed EA topics. For instance, is it generally recognised that GHG emission assessments can benefit from LCT, and that mitigation measures should be determined based on the principles of the mitigation hierarchy. Furthermore, the guidance documents agree that uncertainties should be described with a high degree of transparency. However, deviations among the guidance are also present. For instance, the Danish guidance documents do not highlight the benefits from LCT. Additionally, deviations are also present in relation to how rigorously guidance for individual EA topics are described. For instance, EIA guidance for the topics; GHG emissions assessments, and uncertainties are described in all the guidance documents.

Table 2.3. Guidance regarding the assessment (EIA) of GHG emissions from relevant guidance documents.

	Environmental Impact Assessment of Projects - Guidance on the preparation of the Environmental Impact Assessment Report [The European Union, 2017a]	**Guidance on Integrating Climate Change and Biodiversity into Environmental Impact Assessment [The European Union, 2013a]**	**Guidance on the law on environmental assessment of plans and programs and of specific projects - specific projects [The Danish Environmental Protection Agency, 2022a]**	**Assessing Greenhouse Gas Emissions and Evaluating their Significance [IEMA, 2022]**	**Climate Change in Impact Assessment: International Best Practice Principles [IAIA, 2018]**
Baseline	The baseline should define how the current state of the environment is expected to change with the implementation of the project. The baseline should be a dynamic baseline, taking climate changes over time into account.	The Baseline should define how the current state of the environment is expected to change with the implementation of the project. Especially for long term projects, the baseline should be an evolving baseline, by taking climate changes into account.	A detailed description of the baseline and its likely development if the project is not constructed. The description must contain specific parameters e.g. physical characteristics.	The report should include a description of the current baseline, the future base, and the alternative baseline. The overall goal of the baseline is being able to assess the net GHG impact.	
Environmental targets	The assessment should take relevant GHG reduction targets into account, plus assess to what extent the project contributes to achieving these targets.		Take into account relevant environmental protection objectives from EU and/or individual member states.	Include how the project contributes to the fulfillment of relevant climate goals.	National or relevant sectoral climate objectives should be identified and used.
GHG emissions assessment	The assessment should include direct and indirect GHG emissions. A life cycle assessment could be conducted in order to calculate the emissions magnitude. Additionally the assessment should include the characteristics of the whole project including construction and operational phases, and if relevant demolition as well.	The assessment should include direct and indirect GHG emissions. A life cycle assessment could be conducted in order to calculate the emissions magnitude.	The assessment of GHG emissions needs to include the emissions associated with the construction and existence of the project, and where relevant demolition activities. Additionally, the assessments should take into account the likely duration, reversibility, cumulative effects, trans-boundary effects, and positive or negative effects of the project.	A detailed GHG emission assessment typically covers all project phases. In some cases, certain life cycle phases can be excluded from the assessment due to the project's scale. These exclusions need to be clearly highlighted and justified. Alternatively, a qualitative assessment can also be accepted.	The magnitude, composition, and intensity from each project phase must be estimated and should be assessed through a life cycle approach. Quantitative analysis is desired, however qualitative approaches can suffice in some cases.

Mitigation measures	The principles from the mitigation hierarchy should be applied. The effectiveness of recommended measures should be described along with their expected reliability and certainty.	It is recommended to eliminate GHG emissions before they occur so mitigation measures are less relevant. It should be noted that mitigation measures can themselves induce GHG emissions.	The principles from the mitigation hierarchy should be applied.	The principles from the mitigation hierarchy should be applied. Mitigation measures should be incorporated early rather than bolted on at a later stage.	Mitigation measures should be identified to reduce or avoid direct or indirect GHG emissions.
Determination of significance	The Characteristics of an impact, as well as the values associated with the environmental issues affected, are considered in the significance criteria. The significance determination is context-specific and therefore significance criteria should be customised based on the specific project and its settings	The determination of significance for projects GHG emissions must be context specific.	The concept of significance contains several dimensions: the environment affected e.g. geography and the vulnerability of the area, characteristics of the effects e.g. duration, frequency and reversibility of the effects, and the the assessment method for an impact such as threshold values, expert evaluation, and environmental targets. The significance of the project's environmental impacts is determined based on the description of a reference scenario and its likely evolution if the project is not implemented.	All GHG emissions should be considered as a combined effect and as such, any GHG emission contribution might be considered to be significant. The determination of significance should be based on the projects net impact over its entire lifetime.	
Uncertainty	Practitioners needs to pay attention to uncertainties and in some cases apply new methods or techniques in order to accommodate uncertainties.	Potential uncertainties regarding datasets or applied methods should be considered and thoroughly described so relevant stakeholders and decision makers can take these considerations into account. When communicating uncertainties, complex and obscure language should be avoided.	Potential uncertainties regarding datasets or applied methods should be considered and thoroughly described so relevant stakeholders and decision makers can take these considerations into account.	Potential uncertainties regarding datasets or applied methods should be considered and thoroughly described so relevant stakeholders and decision makers can take these considerations into account. If uncertainties affect the results significantly, additional measures should be taken in order to provide confident results.	The assessment should explain and justify how knowledge about the GHG emissions are obtained. Furthermore, the degree of confidence and validity that can be placed on the results, needs to be described.

Table 2.4. Guidance regarding the assessment (SEA) of GHG emissions from relevant guidance documents.

	Implementation of Directive 2001/42 on the Assessment of the Effects of Certain Plans and Programmes on the Environment [The European Union, 2004]	**Guidance on Integrating Climate Change and Biodiversity into Strategic Environmental Assessment [The European Union, 2013b]**	**Guidance on the law on environmental assessment of plans and programs and of specific projects - plans and programs [The Danish Environmental Protection Agency, 2022b]**	**Climate Change in Impact Assessment: International Best Practice Principles [IAIA, 2018]**
Baseline	The assessment must include a description of the current state of the environment in order to understand how the plan or programme could significantly affect the environment	The assessment should describe the evolution of the baseline meaning how the current climatic state is expected to change with or without the plan/programme	A description of the baseline and its likely development if the plan/programme is not implemented.	
Environmental targets		Describe how the plan/programme contributes to relevant international and national climate goals.	In order to clarify the plan/programmes interaction with established planning, the assessment needs to describe relevant environmental protection goals at both international, regional and local level.	National or relevant sectoral climate objectives should be identified and used.
GHG emissions assessment	The assessment should take into account the impacts' likely duration, frequency, reversibility, transboundary, cumulative effect, risk of human health, impact magnitude and the vulnerability of the area likely to be efected	The assessment should include direct and indirect GHG emissions. A life cycle assessment could be conducted in order to calculate the emissions magnitude.	The assessment should take into account the impacts' likely duration, cumulative effect, permanent or temporary character, and if the impacts are positive or negative.	The magnitude, composition, and intensity from the each plan/programme life cycle phase must be estimated and should be assessed through a life cycle approach. Quantitative analysis are desired, however qualitative approaches can suffice in some cases.
Mitigation measures	Mitigation measures can have negative environmental consequences, which should be taken into account	The assessment should engage with the GHG emissions throughout the planning process rather than mitigate them after they occur. The precautionary principle should be applied.	It is recommended that mitigation measures are formulated as specific as possible so the intention is clear.	Mitigation measures should be identified to reduce or avoid direct or indirect GHG emissions.
Determination of significance		On a global level the impact may be insignificant, however on a local and regional level the impact may be significant, therefore the determination of significance should be context specific.	The concept of significance contains several dimensions: the environment affected e.g. geography and the vulnerability of the area, characteristics of the effects e.g. duration, frequency and reversibility of the effects, and the the assessment method for an impact such as threshold values, expert evaluation, and environmental targets.	

Uncertainty	Several uncertainties exist, and insufficient or missing data, and a lack of knowledge may make determining the likely significant impacts difficult. A rough estimate of the effect should, however, always be achievable.	The uncertainties associated with the results and applied methods should be thoroughly described. In order to accommodate uncertainties, several approaches could be taken: - Use qualitative approaches when specific data is missing. - Use scenarios based on trends in the society. - Use the precautionary principle.	Due to the nature of plans/programmes they are more uncertain compared to projects. Therefore it is important to specify these uncertainties.	The assessment should explain and justify how knowledge about the GHG emissions are obtained. Furthermore, the degree of confidence and validity that can be placed on the results, needs to be described.

2.4 Research concerning assessment of GHG emissions

This section touches upon the status of integrating climate change and thereby assessing GHG emission impacts in EA practice. Initially, research concerning Danish EIA is presented, after which these findings are put into a larger perspective covering research from other countries.

Previous studies have shown that assessments of GHG emissions in Danish EA processes are neither comprehensive nor systematic [Larsen et al., 2013; Larsen, 2014; Larsen and Rasmussen, 2014]. More recent studies by the authors of this thesis, focusing on the assessment of GHG emissions in the Danish EIA practice, came to similar conclusions. The findings of these studies are presented in the following section.

The study by Christensen [2022] found that only three out of 16 EIA reports assess all life cycle phases, including: before use, use, and end of life, related to GHG emission impacts. Findings of the study also indicated that impacts in the use phase were included more frequently than impacts related to construction- and demolition. Correspondingly, the study by Munk [2022] also concluded that impacts associated with the demolition phase were rarely included, as it was only identified in one out of 16 EIA reports. The missing inclusion of life cycle phases can lead to assessments based on a misleading or incomplete representation of reality. According to IEMA: *"A detailed and complete GHG emissions assessment typically covers all life cycle modules." [IEMA, 2022,p.16].* Though, the guidance document highlights that certain life cycle phases can be excluded if justified.

Additionally, it was emphasised by both Christensen [2022] and Munk [2022] that there was no systematic approach to determining the significance of GHG emissions. For the majority of construction and building projects, impact significance was determined based on a comparison with the total national GHG emissions and/or municipal emissions [Munk, 2022]. Likewise, Christensen [2022] found that total national GHG emissions were most frequently applied as the reference for comparison. This was emphasised as a problem:

> *"By comparing with the Danish annual emissions, the GHG emissions induced by the project will appear as a very small and insignificant impact regardless project type."* [Christensen, 2022, p.25].

None of the analysed EIA reports determined any GHG emission impacts to be significantly negative, meaning that no mitigation measures were required Christensen [2022]; Munk [2022]. However, EIA reports for eight out of 16 construction and building projects proposed mitigation measures related to either the construction- or operation phase. The most predominantly suggested measures concerned restrictions on idling construction machinery [Munk, 2022]. Generally, the results of the two previous studies show that several issues exist in regard to impact assessment of GHG emissions in Danish EIA reports.

According to international literature, these tendencies are not only present in Denmark, but also in the rest of the world, and occur in both EIA and SEA. Hetmanchuk [2020] assessed the degree to which GHG considerations were included in fifteen environmental impact statements (EIS) for projects across five Canadian jurisdictions, and found that emissions were often compared to provincial or national levels and therefore supposedly insignificant. In this regard, Hetmanchuk [2020] emphasises that:

> *"The comparison of a project's GHG emissions to regional, national or global levels does not determine the significance of an effect and should not be used as such (...) All GHG emissions should be considered significant since climate change is a global issue and contribution is not dependant on geography."* [Hetmanchuk, 2020, p.190]

It was further emphasised that all of the reviewed EIS lacked thresholds or targets for GHG emissions, which could be used to describe how the projects can help accommodate reduction targets [Hetmanchuk, 2020]. In another study, do Nascimento Nadruz et al. [2018] examined SEA practice for sectoral and regional planning in Brazil, focusing on the level of integration of climate change issues in 35 SEA reports. The study concludes that the integration of climate change issues in SEA *"can be considered limited and disappointing"* and *"is far from being considered adequate"* [do Nascimento Nadruz et al., 2018,p. 52]. The findings obtained in the Canadian and Brazilian context are generally comparable to what has been reported by other studies covering the SEA practice in England and Germany, Indonesia, and China [Wende et al., 2012; Umam, 2021; Yang et al., 2021].

Even though several countries and international organisations have developed and introduced various policies, regulations, and guidelines for the integration of climate change considerations into EA processes (as touched upon in section 2.3), there still is a need for more systematic approaches and effective tools to do so [do Nascimento Nadruz et al., 2018; Yang et al., 2021]. In this regard, Hetmanchuk [2020] explains:

> *"Clear, concise and complete guidelines should be provided to a proponent to standardize GHG assessments for EA; these may include the types of emissions considered, specific quantification methods, a mitigation hierarchy, thresholds, and entry points for consideration."* [Hetmanchuk, 2020, p.190]

However, a barrier is that the development of incorporating climate change mitigation in EA often has occurred separately across jurisdictions and not jointly [Mayer, 2018]. According to the European Commission's evaluation of the SEA Directive in 2019, climate change mitigation was one of the environmental factors considered least consistent with the SEA Directive [The European Commission, 2019]. This indicates that the SEA Directive does not contribute optimally to the management of climatic factors, which supports the need for more elaborate guidelines.

Even though both the SEA Directive (2001/42/EC) and the EIA Directive (2011/92/EU as amended by 2014/52/EU) require assessments of "climatic factors", research indicates that there currently is no well-established approach to doing so. Generally, GHG emissions assessments are inadequate, and the approaches to determining significance result in distorted assessments when emissions are compared to national levels. Thus, there is a need for more comprehensive and standardised assessments. These should take into account all relevant life cycle phases, use appropriate methods to determining significance, and include considerations of the mitigation hierarchy.

2.5 Sub-conclusion

In summary, EA processes hold great potentials in terms of ensuring that climate change-related issues from proposed PPPs are evaluated and presented to decision makers. As presented by figure 2.1, there is a multitude of entry points for climate change considerations, meaning that issues can be accommodated throughout EIA and SEA procedures. Regarding how practitioners should engage the task of GHG emissions assessment, the majority of guidance documents promote the inclusion of LCT. Thus, LCT are perceived as a beneficial contribution to the assessment of GHG emissions. However, in terms of how to approach the determination of impact significance, only few documents present any practical advice, indicating a lack of knowledge and/or established practice in this regard. This correlates with existing research, as several authors have identified a lack of a systematic approach to significance determination of impacts on GHG emissions. Additionally, researchers also highlight a lack of focus on the inclusion of all life cycle phases. Overall, these notions indicate room for improvement within the assessment of GHG emissions in EA, specifically in regard to inclusion of LCT and significance determination.

2.6 Research question

This section presents the research question of the study and the associated sub-questions. Based on the previous acknowledgements, the following main research question has been developed:

How can life cycle thinking contribute to improving assessments of GHG emission impacts in environmental assessment?

2.6.1 Sub-questions

To answer the main research question, three sub-questions were developed, which are presented and elaborated on in the following.

1. What is the current Danish practice of assessing GHG emissions impacts?

To determine how LCT can improve environmental assessment of GHG emission impacts, it is deemed relevant to first examine the current practice of assessing impacts of GHG emissions in a Danish context. This includes an analysis of the GHG emission impacts assessments carried out in recent EA reports, with a focus on the significance determination and inclusion of life cycle phases. Additionally, experiences and perspectives from Danish EA practitioners are included in order to gain insights into how practice is perceived and shaped.

2. What are the potential benefits and limitations to applying LCT for EA purposes, and to what extent is LCA applied in practice?

The purpose of the second sub-question is to explore the prevalence of LCT in EA processes. This includes a literature review of relevant articles, which aims to explore the benefits and limitations of applying LCT in an EA context. Furthermore, a survey is prepared and distributed in order to obtain a better understanding of Danish EA practitioners' knowledge and experience regarding LCA. Finally, the extent of LCA application in current EA practice is explored thorough text analysis of relevant reports. This aims at presenting the current state of practice, and at understanding of how LCA is applied.

3. How can LCT be applied in assessing GHG emission impacts in EA?

The aim of the third sub-questions is to exemplify how LCT can be applied, in order to accommodate the issues identified through the previous sub-questions. Two cases are explored as actual examples of EA practice, thus demonstrating the potentials of applying LCT and LCA for GHG assessment purposes, and the experiences are reflected upon. It is noteworthy that LCT and LCA is distinguished upon in this regard. In this thesis, LCT is understood as a means of considering PPPs based on a systems perspective, whereas LCA is understood as a tool for calculating the emissions that occur in that system. In other words, LCT is considered as the under laying considerations upon which the LCA is being conducted.

3 Research Design

In this chapter, the research design of this thesis is presented. The aim is to provide an overview of the structure of the research, and to elaborate on considerations related to fulfilling the overall purpose of the research. Initially, a table describing the correlation between sub-questions, theory, methods, and data is presented. Then, reflections on the philosophy of science and scientific theoretical approach are made. The report is structure also presented before going into detail with the applied methods, and how these are utilised throughout the thesis. Finally, a theoretical framework for the discussion of institutional views on practice is presented.

A research design is a plan for how the research will be carried out, and therefore concerns the provisional decisions taken in the initial stages of the research [Farthing, 2016]. Table 3.1 presents an overview of the research design, including research questions, the theoretical approach applied, and the methods and data used.

Sub-questions	Theoretical approach	Methods	Data
1. What is the current Danish practice of assessing GHG emissions impacts?		Survey	60 respondents
	Grounded theory (analytic)	Text analysis	51 EIA reports, 51 SEA reports
2. What are the potential benefits and limitations to applying LCT for EA purposes, and to what extent is LCA applied in practice?		Literature review	16 articles
		Survey	59 respondents
		Interview	4 interviewees
		Text analysis	276 EA reports
3. How can LCT be applied in assessing GHG emission impacts in EA?		Experiment	EIA report: "Upgrading of 55 (Nykøbing F - Sydmotorvejen)"
			"Expansion of Mariagerfjord wastewater treatment plant"
		LCA	EIA report and background data from Ecoinvent 3.6

Table 3.1. Overview of research design including the theories, methods, and data applied to answer the sub-questions

3.1 Philosophy of science

Research is influenced by assumptions about how research should be carried out as well as assumptions about the nature of social phenomena [Bryman, 2012]. Therefore, an outlining of the epistemological[1] and ontological[2] considerations undertaken will provide an understanding of the presuppositions and fundamental conditions forming this thesis.

The thesis takes point of departure in post-positivism, where knowledge is assumed to be part of an ongoing construction, and therefore not perceived as entirely objective due to researchers' prior assumptions about the phenomena under investigation [Farthing, 2016]. Knowledge is not only seen as something derived from data and logic, but can for instance also be derived from subjective experiences. The researchers' way of seeing the world is assumed to affect their research. Therefore, the research produced by the authors of this thesis is influenced by the authors' position in the field. All of the authors have experience with both the EA and LCA discipline, however, knowledge of the advantages related to LCA led to it being favored. The authors became aware of their own bias and tried to apply a more critical reflection of the tool throughout the research.

This thesis' ontological position builds upon constructivism, i.e. that social entities are believed to be social constructions produced through interactions and perceptions of social actors and are thereby under constant revision [Bryman, 2012]. As an example significance is perceived as a social construct, which is determined based on a collective interpretation of what environmental impacts entail. Therefore, the EA practice is seen as a phenomena continually being reshaped by its social actors.

3.1.1 Scientific theoretical approach

The scientific theoretical approach applied in this thesis is mainly based on an abduction form of logical reasoning as the study seeks to build new theory, while also incorporating existing theory where appropriate. An abductive approach combines induction and deduction and thereby enables a back and forth movement between theory and data [Saunders et al., 2013]. Typically, abduction begins with an observation of a 'suprising fact' and then seeks to identify a plausible reasoning for this phenomenon [Saunders et al., 2013].

Through the initial research (presented in chapter 2), it was observed that GHG emission assessments in an EA context often lack systematic approaches to determining significance, and a focus on inclusion of all life cycle phases. This was seen as a 'surprising fact' since the purpose of EA is to provide a solid foundation for decision making that accounts for relevant environmental concerns. Abductive reasoning was deemed relevant in this regard as there could be many possible explanations for this phenomena. The starting point of the research was to collect and interpret empirical data through grounded theory in order to further examine the shortcomings of the EA practice of GHG emissions assessments. Subsequently, an experiment was conducted with the purpose of theory building (providing new knowledge regarding the potentials of LCT application in EA). Lastly, institutional theory was applied to discuss what could affect the EA practice.

[1] Epistemology concerns what is considered as acceptable knowledge within a discipline [Bryman, 2012].

[2] Ontology concerns the nature of the social entities i.e. the phenomena under investigation [Bryman, 2012].

3.2 Report structure

Figure 3.1 presents an overview of the report structure, including the relation between research questions, methods, and theories.

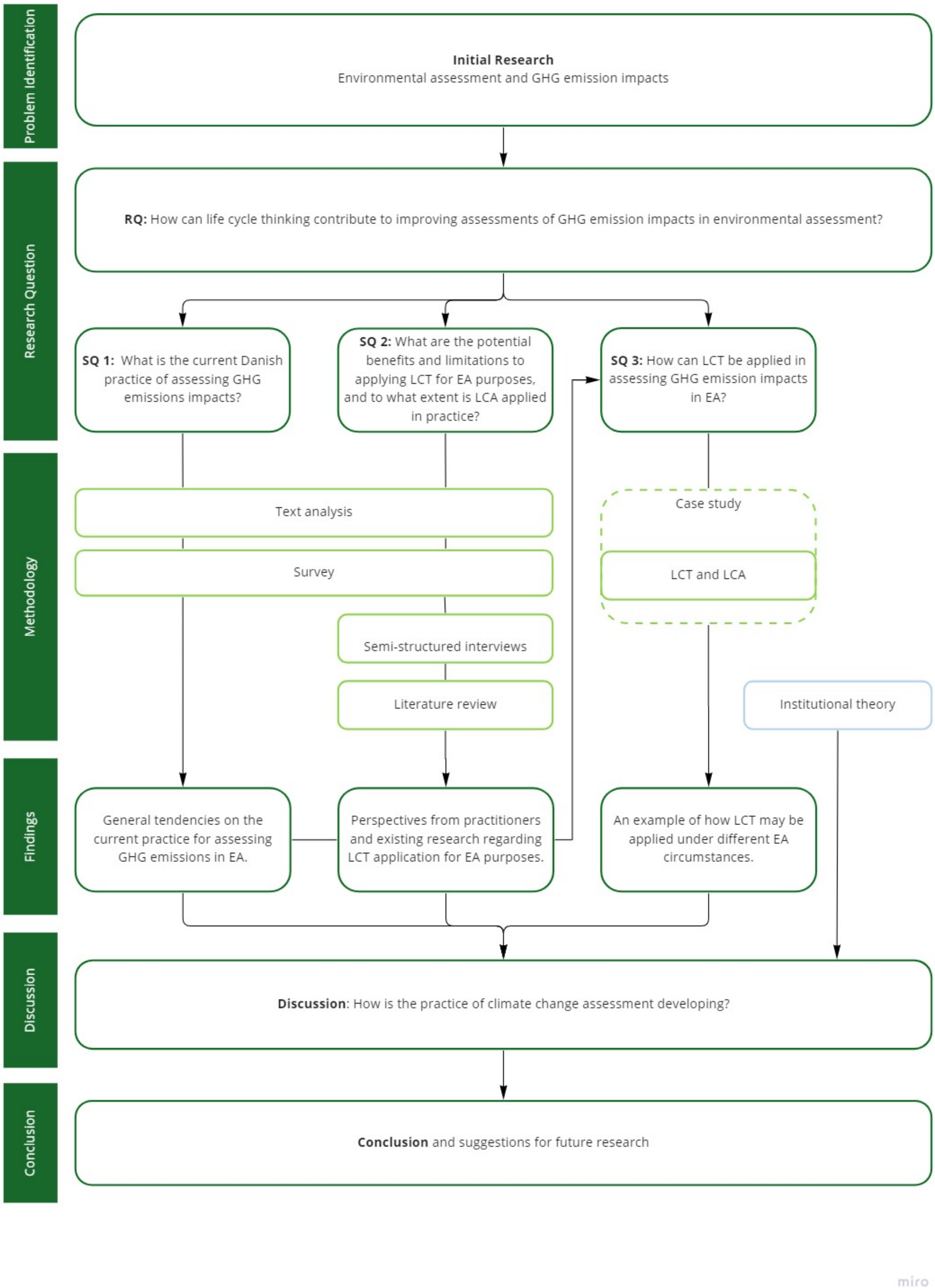


Figure 3.1. Illustration of the research design, including the structure of the report. Light green boxes = methods. Light blue boxes = theories.

3.3 Methodology

In this section the methods applied throughout the thesis will be presented. This includes a brief overall description of the individual methods, followed by considerations regarding the purpose of applying each method. The methods presented in this section include literature review, semi-structured interviews, survey, text analysis, and experiment. The LCA approach, which is applied in chapter 6, is presented in section 6.1.1.

3.3.1 Semi-structured literature review

The literature review has been recognised as a useful method for creating a scientific foundation based on existing publications within a specific field of research [Snyder, 2019]. Besides identifying and synthesizing existing publications, literature review can uncover potential areas where more knowledge is needed, thereby ensuring the relevance of a study. In this study, literature review has been applied as a method for identifying publications within the field of LCT application in EA. In order to ensure a rigorous and effective review, an approach presented by Snyder [2019] was used as a guideline. This encompasses with four overall review phases:

- **1st phase: Designing the review**
- **2nd phase: Conducting the review**
- **3rd phase: Analysing**
- **4th phase: Writing the review**

The review approach applied in this paper resembles what Snyder [2019] defines as the "semi-systematic review". This approach has the aim of gaining an overview of the topic, including common themes, trends and historical development of research.

Phase 1: Designing the review

The first phase of the review concerns the design choices. More specifically, this entails the development of a search strategy, including the selection of search terms, databases, and inclusion/exclusion criteria [Snyder, 2019]. The search terms were selected based on the overall aim of the literature review i.e. identifying literature on LCT application within EA. In selecting the terms, the focus was to ensure that the search would yield the most relevant articles. This was done by narrowing the search parameters to only include terms and phrases appertaining to LCT, EIA and SEA. The following search terms were selected:

Search topics	Search terms
LCT	LCT, life cycle thinking, LCA, life cycle assessment, life cycle analysis
EIA	EIA, environmental impact assessment
SEA	SEA, strategic environmental assessment
Other	~~EA,environmental assessment~~, ~~IA~~, ~~impact assessment~~, ~~EIS~~, ~~environmental impact statement~~

Table 3.2. Selected search terms

As is evident from the list of search terms, they only include slight variations of the main search topics. The final choice of search terms was based on an initial search that including a broader range of terminology (these terms are crossed out in table 3.2). However, this search yielded a large proportion of publications that were deemed irrelevant.

An explanation could be that while terms like "impact assessment" or "sustainability assessment" can be used to describe EIA and SEA, these also encompass a variety of other procedures and methods.

The choice was made to only use the search field "Title", as a test search using the field "Title, abstract, keywords" yielded a large amount of articles that were also deemed irrelevant.

The selected databases were *Science Direct* and *Scopus*, as these are trusted, publisher-independent citation databases. Initially, no limit was set regarding publication date, as there was no preliminary knowledge of either the amount or the history of publications. The search was limited to publications in English.

These considerations resulted in the formulation of a search string (Table 3.3).

Search field	Search string
Title	LCA OR LCT OR "life cycle thinking" OR "life cycle analysis" OR "life cycle assessment" AND EIA OR "environmental impact assessment" OR SEA OR "strategic environmental assessment"
Filters	• Language: English • Peer reviewed articles only

Table 3.3. Criteria for the search string. "" is an indication of a locked phrase)

Phase 2: Conducting the review

The second phase of the review concerns the practical plan for selecting the articles and the actual selection [Snyder, 2019]. The final search string yielded 76 articles in *Scopus* and 28 in *Science Direct*, giving a total of 104 articles. The review of these was conducted in several stages. Firstly, a preliminary screening was carried out based on the articles' titles and abstracts in order to remove irrelevant articles. In *Scopus*, 54 articles were removed because they exclusively focused on LCA or used the terminology "environmental impact assessment" to cover other procedures or methods than EIA. 14 articles was sorted out from *Science Direct* for similar reasons. The remaining 36 articles were added to the reference manager *RefWorks*[3], which was used to manage the review. The articles were then systematically checked for recurrences, leaving a total of 28 articles. Afterwards, the articles were screened in detail to ensure relevance and compliance with the aim of the review. This final step resulted in the selection of eight articles. The main reason for articles being sorted out in this step was because of an explicit focus on LCA. Additionally, a few did not fit the scope of the study and some were not accessible.

In order to identify potentially overlooked literature, cross-referencing and snowball sampling was carried out, meaning that references in the selected articles were checked for potentially relevant literature. The identified literature underwent the same stages as the articles in the primary search, and yielded an additional eight articles. In total, the review yielded 16 articles.

An overview of the review is presented in table 3.4.

[3]https://refworks.proquest.com/researcher/

Step	Stage	How	
1	Database	Scopus	ScienceDirect
2	Filtering	Key phrases: ("strategic environmental assessment" OR SEA OR "environmental impact assessment" OR EIA) AND ("life cycle assessment" OR LCA OR "life cycle thinking" OR LCT OR "life cycle analysis") In Article title; Language: English	
3	Search	Papers searched in Scopus: N = 76	Papers searched in Science Direct: N = 28
4	Preliminary screening based on title and abstract	Papers after removal of irrelevant theme: N = 22	Papers after removal of irrelevant theme: N = 14
5	Merge	Papers after removal of duplicates: N = 28	
6	Detailed screening based on relevance	Papers after detailed screening: N = 3	Papers after detailed screening: N = 5
7	Supplement	Cross-referencing and snowball sampling: N = 8	

Table 3.4. Identification of publications via databases. N = amount

Phase 3: Analysing
The third phase of the review concerns the means to conduct an appropriate analysis, including the extraction of relevant information from the articles [Snyder, 2019]. Throughout the review, a set of characteristics were identified and used as a guidance for the analysis. The characteristics are further described in table 3.5.

Characteristics	Description
Title	The title of the article
Country	The country in which the study is rooted (where the data for the study has been gathered)
Aim	The objective of the article
Methodology	The approach and methods used in the article
Benefits	The advantages of integrating LCA in EIA/SEA according to the article
Limitations	The limitations of integrating LCA in EIA/SEA according to the article
Knowledge gap	The potentials for future research based on the article
Framework	Specific information on how LCA can be incorporated in the different EIA/SEA steps

Table 3.5. Characteristics of the selected publications

For the analysis, the articles were read through and information related to each of the characteristics was transferred to a table. If additional information was found relevant, it was added in a new column. Hereby, all relevant information from the articles was gathered in one place, which made it easier to identify similarities, differences, and knowledge gaps. A table showing the characteristics: title, country, aim of the study, conclusions and reference, can be found in appendix A.1.

Phase 4: Writing the review
The aim of the fourth phase is to structure and write the review [Snyder, 2019]. The review was structured around the different characteristics and knowledge patterns identified from the table in the third phase of the review. The review is presented in chapter 5.

3.3.2 Survey

Survey is used as a research method for collecting empirical data in this study. Survey is defined as *"a systematic method for gathering information from (a sample of) entities for the purposes of constructing quantitative descriptors of the attributes of the larger* *population of which the entities are members"* [Groves et al., 2009, p.2]. The method has been applied to gain knowledge about the Danish EA practice related to the assessment of GHG emissions and the application of LCA. Therefore, the survey was divided into two parts: one concerning the assessment of GHG emissions, and one related to the application of LCA in EA. The questionnaire is presented in appendix A.2. The survey questions were inspired by the obtained knowledge from existing literature and only consisted of closed questions, meaning that the respondents were provided with predefined responses. The raw data collected through the survey can be found the attached in annex, in the sheet labelled "Survey data".

In the first part of the survey regarding GHG emissions, the respondents were asked whether they had been a part of an EA process where GHG emissions were assessed. This was done in order to clarify how many have practical knowledge regarding the assessment of GHG emission impacts. Additionally, the respondents were asked about the quality of these assessments as this was identified as a shortcoming by earlier studies. Correspondingly, a question was related to whether the practitioners experience a demand/push for improving the assessments of GHG emissions in order to gain insight of the development within the field. The last two question concerned the practitioners' knowledge of relevant methods and their opinions of the methods' sufficiency.

For the second part of the survey regarding LCA, the respondents were asked to what extent they have knowledge of LCA and to what extent they have used it as a tool in EA processes. The aim of these questions were to gain knowledge about the extent to which the tool is applied for EA purposes. In order evaluate the need for a quantitative tool such as LCA, and to compare the answers to findings in literature, the respondents were asked to what extent they believe that the assessments of GHG emissions need to be more data-driven. To evaluate the push-pull dynamics identified during the state-of-the-art, the respondents were lastly asked to what extent they experience a push for applying LCA in assessments of GHG emissions in EA.

The survey was conducted in two rounds as both a printed questionnaire and as a web survey (online). The first survey was carried out on the 18th of March in relation to a supplementary EA training course organised by Aalborg University and The Danish Centre for Environmental Assessment (DCEA). The survey was distributed to the participants of the course and yielded 21 respondents. The responses from physical survey were then added to Survey-xact in order to make common statistics with the corresponding online survey. The online survey was active from March 28th to April 28th and yielded an additional 39 respondents. The survey was conducted in Survey-xact[4] and was posted to the LinkedIn pages of DCEA and the Dreams project[5]. In order to increase the number of respondents, the survey was also posted on internal platforms of the three consultancy companies: COWI, NIRAS and Ramboll.

The survey which was posted on LinkedIn was open access which entailed a risk of individuals without an EA background answering the survey. In order to accommodate this risk of data uncertainty, the survey introduction clarified the purpose and specified

[4]A leading tool for online surveys in Scandinavia - `https://www.surveyxact.dk/`

[5]DREAMS is a research project funded by Innovation Fund Denmark, with the goal of improving EA practice through digitization `https://dreamsproject.dk/`

the targeted respondents of the survey.

In total, the survey yielded 60 respondents, out of which 59 completed the whole survey, and 1 only answered the first part related to GHG emissions. The respondents were primarily consultants (63 %), developers (13 %), and from municipalities (12 %).

3.3.3 Semi-structured interviews

Semi-structured interview was used as a method to gather empirical data, as it enables a dynamic dialogue in regard to a specific topic [Brinkmann and Kvale, 2018]. Four semi-structured interviews were carried out with the objective of gathering nuanced perceptions on the application of LCT/LCA in EA processes. This included obtaining knowledge on challenges and opportunities for improvement recognised by researchers and a practitioner.

The chosen approach for all interviews was the semi-structured interview, as it can allow for new emerging perspectives to be introduced, and for the interviewer to ask followup questions and thereby contribute to a more dynamic dialogue [Brinkmann and Kvale, 2018]. One general interview guide was prepared and adapted for each interview as a tool to steer the conversation and to help ensure that the aim of the study was maintained. The general interview guide is presented in appendix A.3.

Name	Profession	Date	Language	Duration	Rationale
Anna Björklund	Chemical Engineer and Professor in Environmental Strategic Research	March 10th 2022	English	35 minutes	Gaining perspectives on LCA as a tool in EA from an LCA researchers perspective
Pyrène Larrey-Lassalle	Engineer and PhD in Environmental Assessment (specialised in LCA)	March 24th 2022	English	25 minutes	Gaining perspectives on LCA as a tool in EA from an LCA researchers perspective
Morten Bidstrup Ramshev	Project Manager within EA at COWI	March 28th 2022	Danish	1 hour, 10 minutes	Gaining perspectives on LCA as a tool in EA in a Danish context from an EA researchers perspective and exploring the current practice
Bo Weidema	Professor at Aalborg University at The Danish Centre for Environmental Assessment (specialised in LCA)	April 12th 2022	Danish	30 minutes	Gaining perspectives on LCA as a tool in EA in a Danish context from an LCA researchers perspective

Table 3.6. Overview of interviewees

Each interview was transcribed by transcription software in Microsoft Word and was then gone through manually to ensure a better understanding of the content of each interview, and to create an overview of the empirical data. Quotes used from the Danish interviews were translated to English which can potentially have cause alterations of the intended meaning.

Uncertainties

It is questionable whether the interviews with the four LCA/EA researchers actually resulted in a nuanced understanding of how LCT/LCA is applied in EA processes. Because three of the interviewers had limited knowledge about EA, the information gathered was quite skewed. It would have been beneficial to interview EA practitioners to acquire their opinions on the issues associated with the practice of assessing GHG emissions. However, Morten Bidstrup Ramshev is both a researcher and a practitioner, and therefore provides some of these perspectives. In addition, interviewing an authority could have been useful to get their perspectives on the matter, including their role, intentions, and possibilities in regard to GHG emission assessments.

3.3.4 Text analysis

Text analysis has been applied as a method for two overall purposes: To examine the current practice of assessing GHG emissions in EA reports, including the life cycle phases covered and the determination of significance; and to explore the application of the LCA tool in impact assessment of GHG emissions. According to [Roberts, 2000,p. 1] *"Quantitative text analysis refers to the application of one or more methods for drawing statistical inferences from text populations."*. The reports selected for the text analysis and the approaches used are presented in the following sections. The raw data for the analyses can be found in the attached annex in the sheets labeled: "Reports - GHG emission" and "Reports - apply LCA".

In order to carry out the text analysis, it was necessary to first identify EA reports assessing GHG emission impacts. A total of 762 EA reports, published within the last five years (2017-2021) were found through the DREAMS database. These were manually checked for the occurrence of assessments of GHG emissions. The manual inspection included a skim through the table of contents and a word search on the phrases: climate, CO_2, and greenhouse gases. Afterwards, it was checked whether the word or content was related to impact assessment of GHG emissions. The search yielded a total of 276 reports that include impact assessment of GHG emissions.

Analysis of GHG emission assessments
To examine the current practice of assessing GHG emission impacts in EIA and SEA reports, the selection was narrowed down to only including the most recent reports (from 2020-2021). This enabled a sample which included different PPP types across several sectors, and yielded 51 SEA reports and 51 EIA reports (the reports that are combined EIA/SEA were counted as EIA reports, due to the experience that project characteristics are part of the assessments herein).

Grounded theory was then applied as an approach to analyse how the determination of significance was carried out. Grounded theory can be defined as *"a method of conducting qualitative research that focuses on creating conceptual frameworks or theories through building inductive analysis from the data."* [Charmaz, 2006,p. 187]. Grounded theory is hereby a methodology to inductively generate theory by using qualitative data. The first step is to gather data [Charmaz, 2006]. The chapters and sections related to assessment of GHG emission impacts within each report were read through, and text concerning the determination of significance was copied to an Excel sheet. The determinations varied in explicitness, which is why they were initially divided into two categories; 1) significance is determined i.e. the determined degree of significance was clear, and 2) the impact is only characterised i.e. the degree of significance was not defined, but the impact was characterised as e.g. positive/negative, large/small, or direct/indirect. In order to further analyse the gathered data, grounded theory coding was applied. The purpose of coding is to categorise the data by identifying the meaning of each data set Charmaz [2006]. Therefore, the gathered data was looked through with the purpose of categorising significance determination approaches. This was in plenary, in order to ensure that the authors agreed upon the categorisations. The different categories are listed and explained in table 3.7. Additionally, determined degree of significance was noted.

Categories	Description
The zero alternative	The determination of significance is based on a comparison between the GHG emission impacts from the PPP and a future scenario where the PPP is not implemented
Annual emissions comparison	The determination of significance is based on a comparison between the GHG emission impacts from the PPP and annual GHG emissions e.g. annual national and municipal emission or annual emissions pr. inhabitant
Intensity of impacts	The intensity of GHG emission impacts from the PPP is used as reference to determining significance, where intensity is considered at a scale ranking from negligible to significant
Duration of impacts	The significance of GHG emission impacts is determined based on the impact's duration e.g., when it is argued that the construction work is temporary and therefore not significant
No reference	No reference was provided for the determined significance
Comparable PPPs	The determination of significance is based on a comparison between the GHG emission impacts from the PPP and other similar PPPs
Sufficiency of PPP initiatives	The determination of significance is based on a comparison between the GHG emission impacts from the PPP and the initiatives undertaken to reduce the PPPs' impacts on GHG emissions
Other PPP impacts	The significance of one GHG emission impact is determined based on a comparison with impacts from other phases or activities of the PPP
Climate goals/objectives	The determination of significance is based on a comparison between the GHG emission impacts from the PPP and its effect on climate goals/objectives

Table 3.7. Identified categories regarding the approach to determine significance in EA reports

To analyse which life cycle phases the assessment of GHG emission impacts include, predefined phases were used to categorise the data, deriving from Thrane and Schmidt [2007a]. These include; extraction of raw materials; manufacturing/processing; construction; use; and disposal. The chapters and sections related to the assessment of GHG emission impacts within each report were read through, and it was marked in an Excel sheet which of the life cycle phases were included. Additionally, it was noted whether the assessments related to each phase were quantitative or qualitative. Note was also made of the PPP type.

Analysis of LCA application

To examine the current practice, the 276 reports that included impact assessment of GHG emissions were checked for applications of LCA. A search for the words 'life cycle' and 'LCA' was carried out using the search function in Adobe Acrobat, which yielded 66 reports. If the words were not present, it was presumed that LCA had not been applied. It was observed that the phrases were regularly used in other contexts, such as in describing the life cycle of animals. Therefore, the occurrences were subsequently looked through manually, to ensure that irrelevant reports were sorted out. Additionally, it was checked whether the life cycle thinking was related to impact assessment of GHG emissions, as well as how the perspective was incorporated. Overall, 20 reports included a life cycle thinking in relation to impact assessment of GHG emissions.

Uncertainties
The results of the text analysis may to some degree be influenced by the inherent uncertainties of the method. Generally, the analysis is based on subjective assessments carried out by the authors of this thesis, implying that misinterpretations may have occurred. Additionally, the method is also prone to human error, e.g. in managing the large quantity of data. This can potentially have led to incorrect results, as the data for each EA report was handled manually.

It became evident that assessments of GHG emission impacts was often combined with the assessment of impacts on air quality. In some cases, the distinction between the two topics was unclear, which made it difficult to determine which topic conclusions appertained to.

Another uncertainty is related to the analysis of the inclusion of different life cycle phases. It was difficult to determine whether or not the assessments included the life cycle phase "extraction of raw materials", as this phase often was vaguely described. The choice was made not to mark the phase, if it was not explicitly mentioned in the EA report. Moreover, for some types of PPPs it does not make sense to include all life cycle phases. This, for instance, applies to a coast protection projects, which only encompass construction work. Thus, the results can be biased towards certain life cycle phases. In some EA reports, it was difficult to identify the actual determination of significance as it was not explicitly stated. In these cases, an attempt was made at interpreting significance determinations from what was stated in the report. This may have lead to potential misinterpretations that can have influenced the overall results.

Furthermore, in some cases, it was difficult to determine whether LCA was actually applied, or if the application was limited to presenting data from LCA databases. Therefore, judgements had to be made based on the available information in the EA reports. Finally, there is a risk that all of the EA reports that apply LCT have not been identified. One error could be that the applied database (DREAMS) may not include all reports. Another may be that the applied search terms were insufficient in identifying all relevant reports.

A final uncertainty of this method can be attributed to the dataset as some PPP types are more represented than others. An illustration of the PPP types distributed according to the analysed EIA and SEA reports, can be found in appendix A.4. Renewable energy PPPs account for 39 of the 102 EA reports analysed, indicating that they are dominating the dataset. Because renewable energy PPPs may be assessed based on the same selected life cycle phases, this distribution may have influenced the results. Furthermore, renewable energy PPPs will per definition imply GHG emission reductions, which may result in an over representation of positive impacts. Finally, there is a risk that significance determination in renewable energy PPPs are be based on the same comparative references. Overall, this would entail uncertainties related to the results of how significance is determined.

3.3.5 Experiment

An experiment has been conducted in order to demonstrate how LCT may be applied as a means of creating a more sound foundation for the assessment of GHG emission impacts.

The GHG emission assessments in two EIA reports were selected as cases. The reason for selecting cases, was; 1) to exemplify how life cycle phases are included in the assessments, and 2) to illustrate how LCT may contribute to qualifying this. The cases were chosen among the reports analysed in the text analysis, which can be found in the attached annex labeled "Reports - GHG emissions". The following selection criteria were applied, which build upon findings from sub-question 1:

- Fewer than three life cycle phases have been included in the assessment of GHG emission impacts.
- The GHG emission impacts are considered insignificant or minor/small.
- The applied references in determining significance of GHG emission impacts are deemed insufficient.

These criteria were applied in order to select cases, which emphasise the issues related to GHG emission impact assessment (identified in section 4.2), and the potential benefits of applying LCT. Thus, the selection aims to identify what could be characterised as extreme/deviant cases, i.e. cases that are particularly problematic [Flyvbjerg, 2006]. The cases concern a road upgrading project, and an expansion of a wastewater treatment plant, and are further described in chapter 6. The cases are used to conduct an experiment, where the authors of this thesis assume the role of EA practitioners. The authors have some experience with EA having been apart of EA processes, and LCT and LCA modelling having completed courses and applied the tool in previous semester projects. Thereby, it can be argued that the authors to some extent represent actual practitioners.

3.4 An institutional view upon practice

This thesis examines the current Danish practice of assessing impacts of GHG emissions in EA, and the potentials for improvement through application of LCT. However, to understand what constitutes the current practice, and to explore how it is developing, it is deemed relevant to understand the underlying setting. Institutional theory is deemed applicable in this regard, as it can provide a framework for understanding the context in which EA takes place. Thus, institutional theory is used to interpret and discuss the empirical findings from this study, in order to contribute to the understanding of GHG emission assessments in EA.

There are various understandings of institutions and existing literature on the topic provides various definitions that are conflicting in regards to their underlying assumptions [Scott, 2008]. Scott [2008] proposes a broad definition of institutions which can encompass a variety of these differences:

> *"Institutions are comprised of regulative, normative and cultural-cognitive elements that, together with associated activities and resources, provide stability and meaning to social life".* [Scott, 2008,p. 48].

Thus, the central elements that institutions are comprised of are described as regulatory, normative, and cultural-cognitive systems, which Scott [2008] identifies as the "three pillars of institutions". However, the activities that constitute these, and the resources that sustain them, are important as well. Furthermore, behavior contributes to maintaining and modifying rules, norms, and meanings and vice versa. Scott [2008] points out that the three pillars can be seen as contributing to one social framework, but argues the need of differentiating the elements, as they operate through different processes and mechanisms. According to Scott [2008], the three institutional pillars are:

- **The regulative pillar**: The regulative system is based on the fact that *"institutions constrain and regularize behaviour"* [Scott, 2008,p. 52] through regulatory processes such as rule-setting, monitoring, and sanctioning activities. Hereby, force and sanctions are central to the regulative pillar and are often excised through rules and laws [Scott, 2008].

- **The normative pillar**: The normative system encompasses both values and norms, which concern conceptions of the preferred, and what is considered to be the right and appropriate behaviour. Hereby, this pillar defines goals or objectives and the designated appropriate ways to obtaining them. The normative system imposes constraints on social behaviour, though it may also empower and enable action [Scott, 2008].

- **The cultural-cognitive pillar**: The cultural-cognitive system concerns the shared conceptions that designate what reality is, and the conditions that affect how meaning is created. The meaning that is attributed to activities or objects is shaped through words, symbols, and gestures. Hereby, the cultural-cognitive system encompasses how actions or objectives are subjectively interpreted [Scott, 2008].

Based on these acknowledgements, the three pillars of institutional theory are considered as providing a suitable framework for examining the underlying settings for the EA practice of assessing GHG emissions. The regulatory elements of institutional theory are deemed relevant as it focuses on the formal institutional structures i.e. the legal frameworks, which are central for EA practice. Additionally, the normative elements are relevant to be considered as they concern social obligations and expectations which may influence the EA practice e.g. through the public's expectations. Moreover, the cultural-cognitive pillar is relevant as it focuses on the conditions that may constitute or influence habits and understandings, which may be relevant for how EA practitioners assess GHG emissions.

4 The practice of GHG emission assessment

The purpose of this chapter is to obtain knowledge about the current Danish practice of assessing GHG emissions impacts in EA. By doing so, it may be possible to identify potential shortcomings of the current practice, which is analysed based on three main aspects: 1) The experiences and perceptions of Danish EA practitioners, which is explored through a survey. 2) Through text analyses, recent EA-reports are examined with the purpose of investigating the inclusion of different life cycle phases. 3) Significance determination of GHG impacts is explored through text analyses. The objective is to characterise the practice in terms of; the explicitness of determinations, degrees of significance, and the references for comparison applied in determining significance.

4.1 Experience of Danish EA practitioners

In order to obtain further insight into the Danish EA practice of assessing GHG emissions, a survey has been conducted. The objective of the survey was to obtain knowledge about the EA practice related to the assessment of GHG emission impacts through the experiences of practitioners. Additionally, the aim of the survey was to investigate Danish EA practitioners' level of experience regarding LCA application. The results related to the LCA part are presented in section 5.3.2. A thorough description of the applied survey method can be found in section 3.3.2 of the methodology chapter.

The survey yielded 60 responses from practitioners employed by consultancies, developers, governmental agencies, municipalities, etc. The distribution of respondents is shown by figure 4.1:

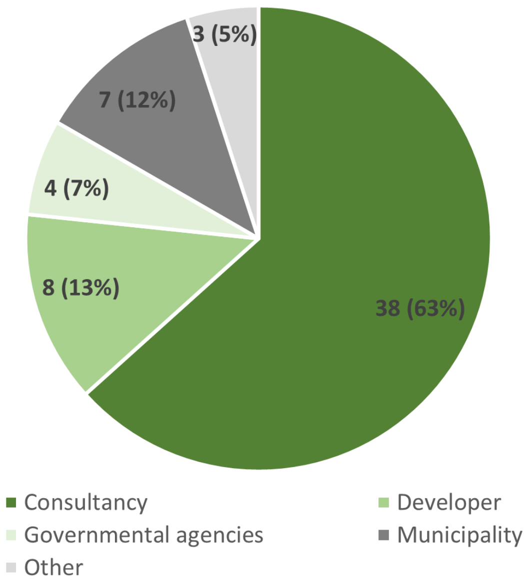


Figure 4.1. Distribution of respondents according to their employers

As presented by the figure, consultants are the most well represented group, accounting for 63% of the respondents, which may be explained by the means of which the survey was distributed.

In order to gain an understanding of the respondents' knowledge of GHG emission assessment, they were asked about their acquaintance with assessment methods, and about their involvement in EA processes. The responses appertaining to these questions are presented in figures 4.2 and 4.3:

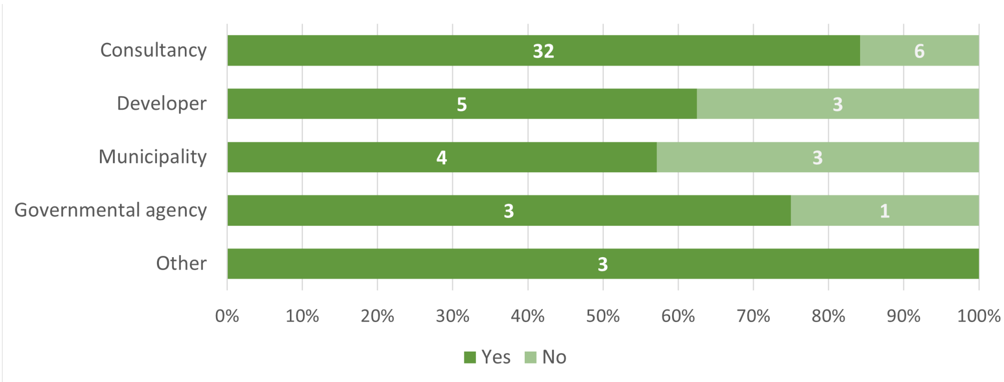


Figure 4.2. Distribution of respondents according to their employer, and to whether or not they have been involved in an EA process, where GHG emission impacts were assessed.

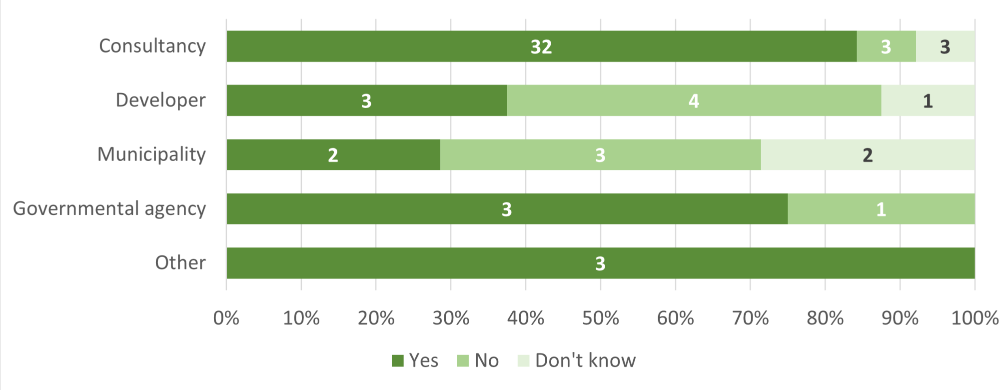


Figure 4.3. Distribution of respondents according to their employer, and to whether or not they are acquainted with GHG emissions assessment methods.

It is evident from figure 4.2 that the majority of respondents replied that they have been involved in an EA process, where GHG emission impacts were assessed, and therefore presumably have some insight regarding the practice. Furthermore, the results indicate that practitioners employed at consultancies are most likely to have been in contact with GHG emissions assessment (apart from the "other" group). As is presented by figure 4.3, the distribution of responses regarding the respondents' acquaintance with assessment methods correlate quite closely to those regarding their involvement. Comparing the figures, it should, however, be noted that a slightly larger proportion of the respondents, employed by municipalities and developers, replied that they are either unacquainted with assessment methods, or that they did not know what to reply. This may indicate that respondents within these two groups have less contact with the actual practice of GHG emission assessment.

Regarding the respondents' perception of 1): the quality of GHG emission assessments, and 2): the accuracy of estimations generated by GHG emission assessment methods, the results are also somewhat in alignment:

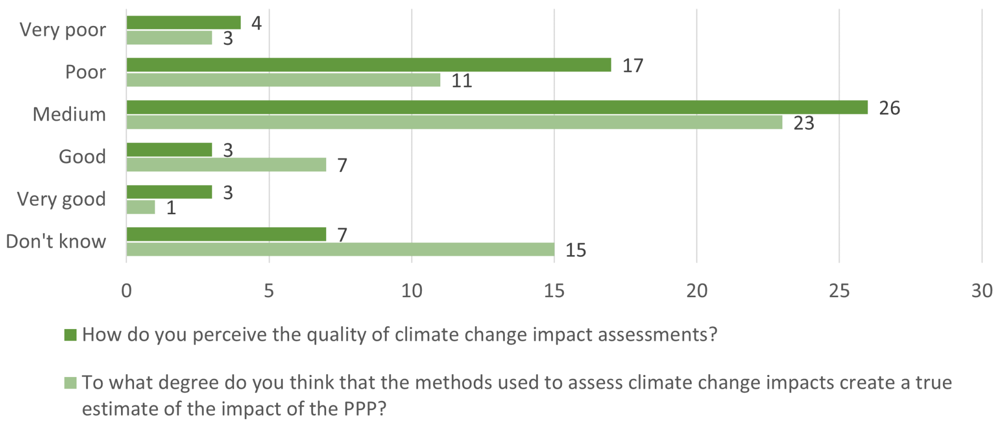


Figure 4.4. Distribution of responses regarding the respondents' perception of the quality of GHG emission impact assessments, and the degree to which they perceive assessment methods as creating a true estimate of impacts.

As presented by figure 4.4, the majority of the respondents (43) perceive the quality of the GHG emission assessments as either medium or poor. The same tendency is present for the question concerning assessment methods. It is, however, also clear that a larger proportion of the respondents did not know the answer to this question, which correlates with the respondents' involvement and knowledge of assessment methods (as presented by figures 4.2 and 4.3. Overall, the answers given to these two questions show that a majority of practitioners have a somewhat negative view on the assessment of GHG emission impacts. This is supported by the fact that 6% of the respondents perceived the quality of assessments as either good or very good, while 13,33% of the respondents replied that they perceived the assessment methods as creating a good or very good estimate of GHG emission impacts.

Finally, the respondents where asked about the degree to which they experience pressure/demand for improving GHG emission assessment. The distribution of replies is presented by figures 4.5 and 4.6:

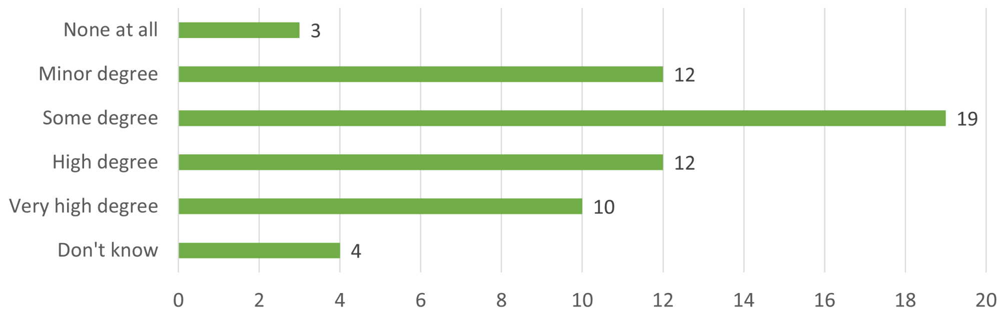


Figure 4.5. Distribution of responses regarding the respondents' experience of pressure/demand for improving assessments of GHG emission impacts.

The results illustrated by figure 4.5 indicate that the respondents experience varying degrees of pressure/demand for improving the assessment of GHG emission impacts. This is exemplified by the fact that the most frequently occurring reply overall, is the experience of some degree of pressure/demand. In addition, there is a somewhat even distribution between the remaining categories. However, the proportion of respondents that have experienced a high or very high degree of pressure, is slightly larger than those who have experienced either a minor degree of pressure/demand or none at all. Overall, this indicates that practitioners do experience some degree of pressure/demand in this regard.

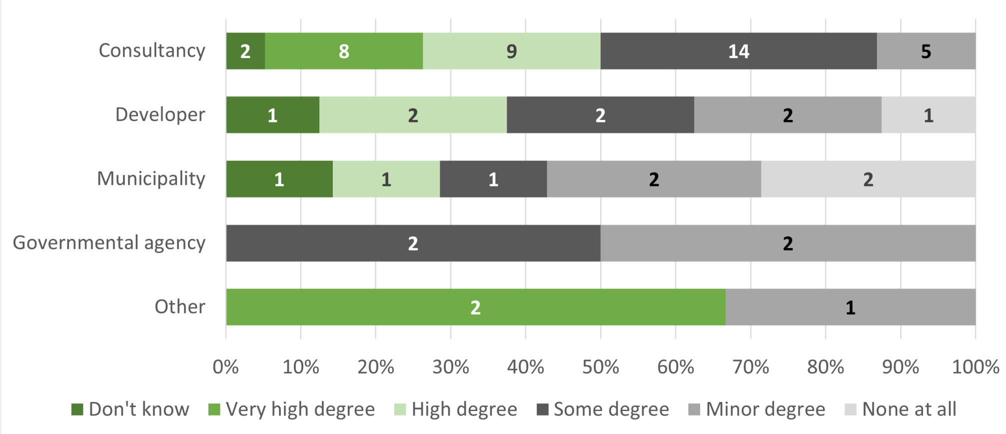


Figure 4.6. Distribution of respondents according to their employer and their experience of pressure/demand for improving GHG emission impact assessments.

When looking at the distribution of responses according to the respondents' employment, it is evident that practitioners employed at consultancies experience a higher degree of pressure/demand than the remaining groups. Almost half of the respondents within this category (17 out of 38), replied that they experience a high or very high degree of pressure/demand, while only 5 replied that they experience a minor degree. In contrast, the respondents employed by municipalities predominantly experience either a minor degree of pressure/demand or none at all. For those employed by developers, the distribution of responses is almost even, while practitioners employed by governmental agencies experience some or a minor degree of pressure/demand.

Tendencies

The results of the survey indicate that EA practitioners generally have some degree of knowledge regarding the assessment of GHG emission impacts, i.e. have been involved in EA processes where GHG emission impacts were assessed, and are acquainted with assessment methods. For both parameters, the responses indicate that consultants have the most knowledge and experience of the responding practitioner groups. Furthermore, the practitioners have an overall negative perception of the quality of assessments, and the preciseness of methods. Thus, these results generally correlate with the findings of the previous studies described in section 2.4. Finally, the results indicate that some degree of pressure/demand for improving assessments of GHG emission impacts exists. However, this is predominantly experienced by consultants.

4.2 Assessments of GHG emissions in Danish EA reports

In order to explore the practice of assessing the impacts of GHG emissions, a text analysis of 51 Danish EIA reports and 51 Danish SEA reports has been conducted. The methodological approach, including the selection of reports, can be found in section 3.3.4. The purpose of the text analysis is: 1) to identify the life cycle phases included in GHG emissions assessments; 2) to determine whether assessments are qualitative or quantitative; and 3) to categorise significance determinations according to the applied reference for comparison.

4.2.1 Included life cycle phases

The results of the text analysis regarding inclusion of life cycle phases are illustrated by figure 4.7 and 4.8:

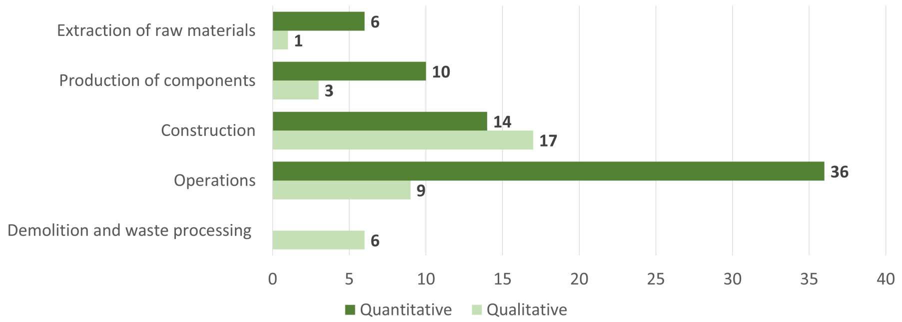


Figure 4.7. Life cycle phases included in EIA reports distributed according to quantitative/qualitative assessments.

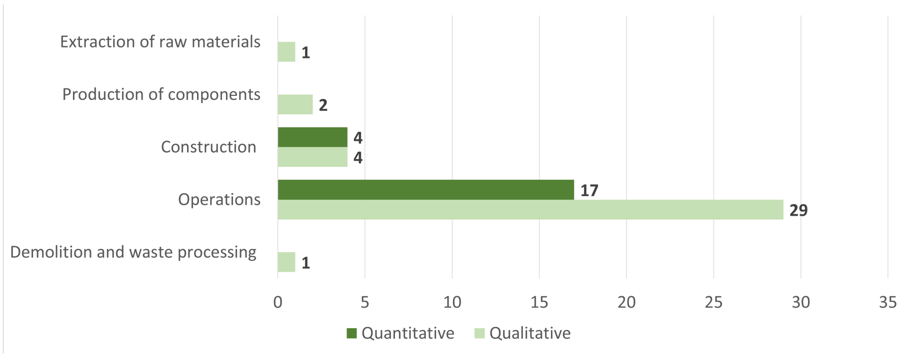


Figure 4.8. Life cycle phases included in SEA reports distributed according to quantitative/qualitative assessments.

As illustrated by figure 4.7, all life cycle phases are to some extent included in the assessments of GHG emission impacts in EIA reports. It is evident that the operations phase is most frequently included, and that the assessments of impacts in the operations phase are primarily quantitative. This characteristic also applies to the phases; production of components, and extraction of raw materials, but these are less frequently included. Construction phase is the second most frequently included phase. For this phase however, the proportions of qualitative and quantitative assessments are more or less equal. The assessments that have been identified as including the demolition and waste processing phase are all characterised as qualitative.

For SEA, the results are illustrated by 4.8. All life cycle phases are covered to some extent, as they are for the EIA reports, however some phases are included more frequently then others. GHG emissions associated with the operations phase are included in almost all SEA reports, as only 5 of the identified reports excluded this phase. The remaining life cycle phases are generally excluded in most reports. The GHG emissions associated with the construction phase are only included in 8 out of 50 reports as the second most included phase. The phase: production of components is only included in 2 reports, while extraction of raw materials and demolition and waste processing are the least included phases, as they only appeared in a single report. Common to assessments across all life cycle phases in the analysed SEA reports, is that these are primarily qualitative.

For EIA reports, the assessments are mostly quantitative, while assessments in SEA reports are mostly qualitative. As described in section 2.3, SEA of plans and programs are often prone to uncertainties, due to the low level of detail. This was also apparent, as some SEA reports included phrases such as:

> *"The fuel consumed for transport and construction machinery emits CO_2. Fuel consumption within the individual excavation areas and in the region as a whole can not be estimated in the planning process".* (SEA: Combined environmental report - Raw materials plan 2020, The Region of North Jutland, 2020, p. 28.)

Due to uncertainties and data with a low level of detail, it can be difficult to provide confident quantitative conclusions, which may be the reason why qualitative assessments are dominant in the SEA reports.

In general, the assessment of GHG emissions vary in terms of how many life cycle phases are included. Figure 4.9 presents an overview of the number of life cycle phases included in the analysed reports.

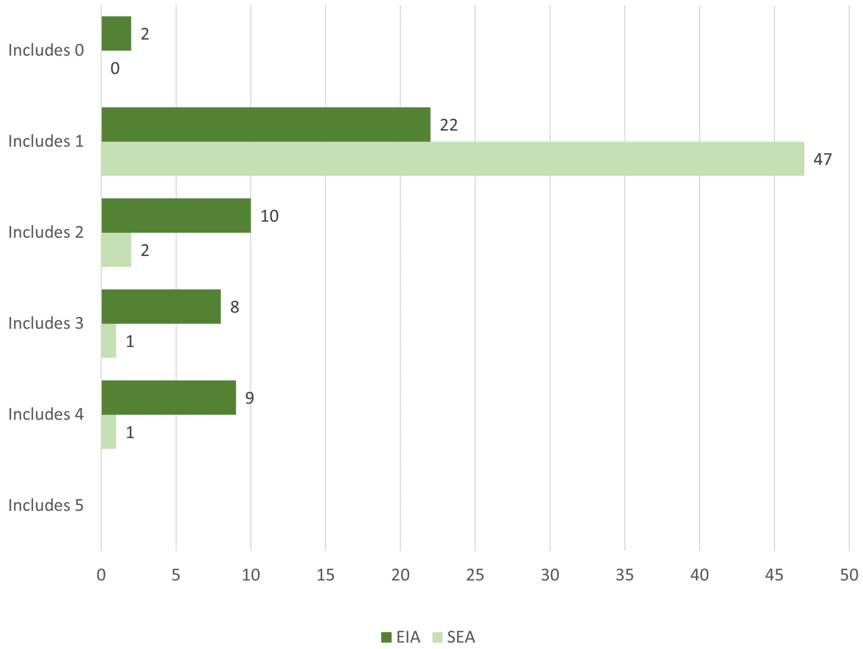


Figure 4.9. The number of life cycle phases included in the assessment of GHG emissions. "0" represents that no life cycle phases are included, while "5" represents that all the presented life cycle phases are included.

As illustrated by figure 4.9, most of the reports include just one life cycle phase in the assessment of GHG emissions. This particularly applies to SEA reports, as 47 out of 50 SEA reports include just one life cycle phase. For EIA reports, 22 out of 51 include just one life cycle phase in the assessments of GHG emissions. This indicates that assessments based on a fraction of the full life cycle of the PPP are predominant within the practice.

It could be argued that this practice is inadequate, as excluding certain life cycle phases may create a distorted image of the impacts' true magnitude. Two of the EIA reports were categorised as not including any life cycle phases at all. The reasoning is that these assessments do not specify whether impacts appertain to certain life cycle phases, i.e. the assessment only addresses the total GHG impact.

Overall, assessments which include 2, 3, or 4 life cycle phases are more predominant in EIA reports, as compared to SEA. However, there are no examples of either EIA or SEA reports that include all 5 life cycle phases in the assessment. This indicates, that it is not common practice to include the entire life cycle of the PPP when assessing GHG emission impacts.

In conclusion, the majority of GHG emissions assessments, in both EIA and SEA reports, include just one life cycle phase, and operations is the most frequently included. This shows that operations is the only life cycle phase which is used to estimate the GHG emissions in many of the assessments. Moreover, none of the EA reports included the entire life cycle of the PPP. Based on these acknowledgements, it could be argued that the missing inclusion of life cycle phases is a prevalent issue in current EA-practice.

4.2.2 Determining significance of GHG emission impacts

As presented in chapter 2, only GHG emissions impacts that are determined to be significant are legally required to be accommodated through mitigation measures. Thus, the determination of significance can be regarded as an important aspect of accommodating GHG emissions from PPPs. Therefore, the practice of determining significance of GHG emission impacts is explored by means of text analysis. A total of 120 quotes concerning the significance of GHG emission impacts have been identified throughout 51 EIA and 51 SEA reports. 77 were found in EIA reports, while 43 were found in SEA reports, indicating that significance of GHG emission impacts is more frequently determined for projects as opposed to plans and programmes. The quotes are interpreted in the following sections.

Explicitness of significance determinations

It is evident from the EA reports and identified quotes that significance is not explicitly determined for all GHG emission impacts. Figure 4.10 illustrates whether the EA reports include a determination of significance or not, while figure 4.11 divides these determinations into two categories according to the explicitness of significance determinations. The first category: "Significance is determined" covers quotes, where the determined degree of significance is clear, i.e. terms such as insignificant, minor/small, moderate, or significant are applied. The second category: "The impact is only characterised" concerns situations, where the degree of significance is not defined, but the impact is characterised as e.g. positive/negative, large/small, or direct/indirect.

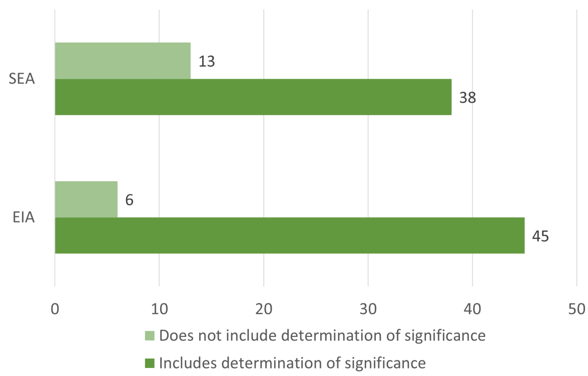


Figure 4.10. EA reports distributed according to whether they include a determination of significance or not

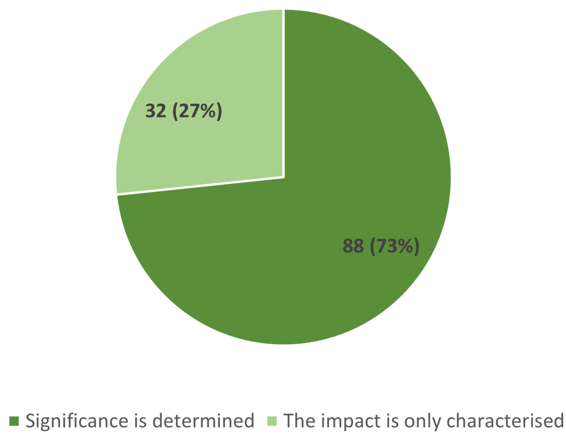


Figure 4.11. Identified significance quotes according to the explicitness of determinations.

As presented by the the figures, the significance of GHG emission impacts is generally determined, and the majority of quotes include explicit determination of significance. It is, however, also apparent that 13 out of 51 (25%) of the SEA reports do not determine significance, and that 27% of the identified quotes do not include explicit determination of significance. This can be criticised, due to the missing emphasis on the severity of impacts. Furthermore, failing to determine significance makes it unclear whether mitigation measures are required.

Degrees of significance

Having established that significance is explicitly determined for the majority GHG emission impacts, it seems relevant to examine the occurrence of different degrees of significance. Figure 4.12 presents an overview of the determined degrees of significance.

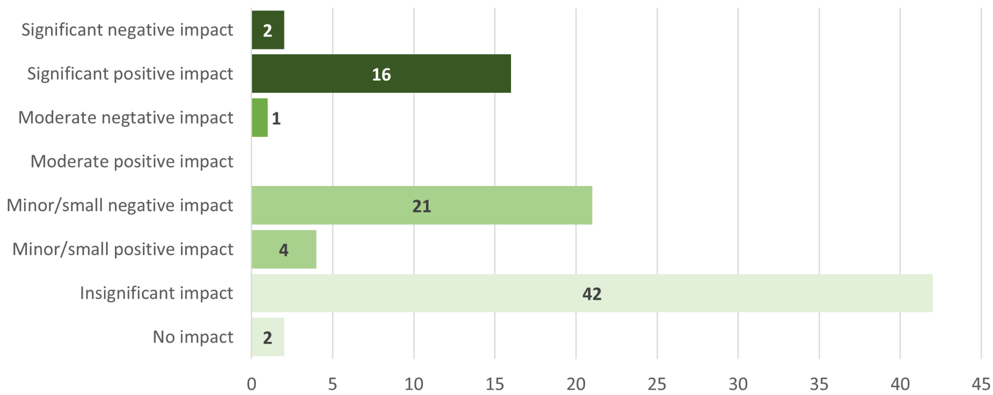


Figure 4.12. Distribution of quotes according to the determined degrees of significance of GHG emission impacts. (N = 120 significance quotes)

As is evident from the figure, around half of the assessed GHG emission impacts are determined to be either insignificant, or having no impact at all. This gives the indication that impacts on climate change rarely are considered significant. Furthermore, the impacts which are determined to be significant are almost entirely positive impacts, i.e. determinations that highlight the environmental gains of implementing the proposed PPP. In this regard, it could be argued that significance determination is used as a way of promoting PPPs that induce positive impacts, while rarely deeming negative impacts significant. This is also supported by the notion that quite a large proportion of negative impacts are determined as being minor/small. It could be argued that this makes these seem more acceptable to decision makers, thereby enhancing the chance of PPP approval.

Significance determination references

Another relevant aspect of the significance determination practice is what the assessments apply as reference for comparison, i.e. what GHG emission impacts of PPPs are compared to when determining significance. The data collected regarding these references is presented through the figures 4.13, 4.14, 4.15, and table 4.1.

Figure 4.13 illustrates a categorisation of significance determinations according to the applied references for comparison. As demonstrated, significance is not explicitly determined for all identified impacts, and therefore the figure only concerns impacts where significance is determined, or where the impact is characterised (in accordance with the results presented in figure 4.11). In addition to the general overview of categories, it is also deemed relevant to determine whether there is a connection between applied categories of reference for comparison, and the types of PPPs. Therefore, figure 4.14 presents an overview of reference categories according to PPP types.

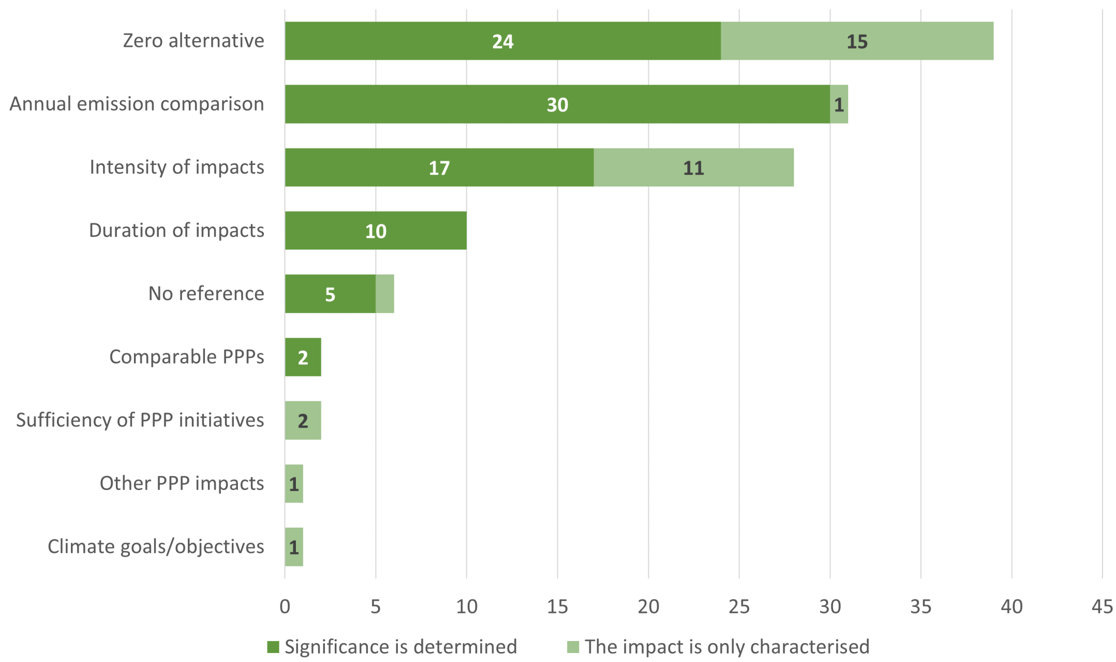


Figure 4.13. Categorisation of references for comparison applied for determining significance of GHG emissions (based on quotes). The quotes are distributed according to the explicitness of determinations. (N = 120 significance quotes)

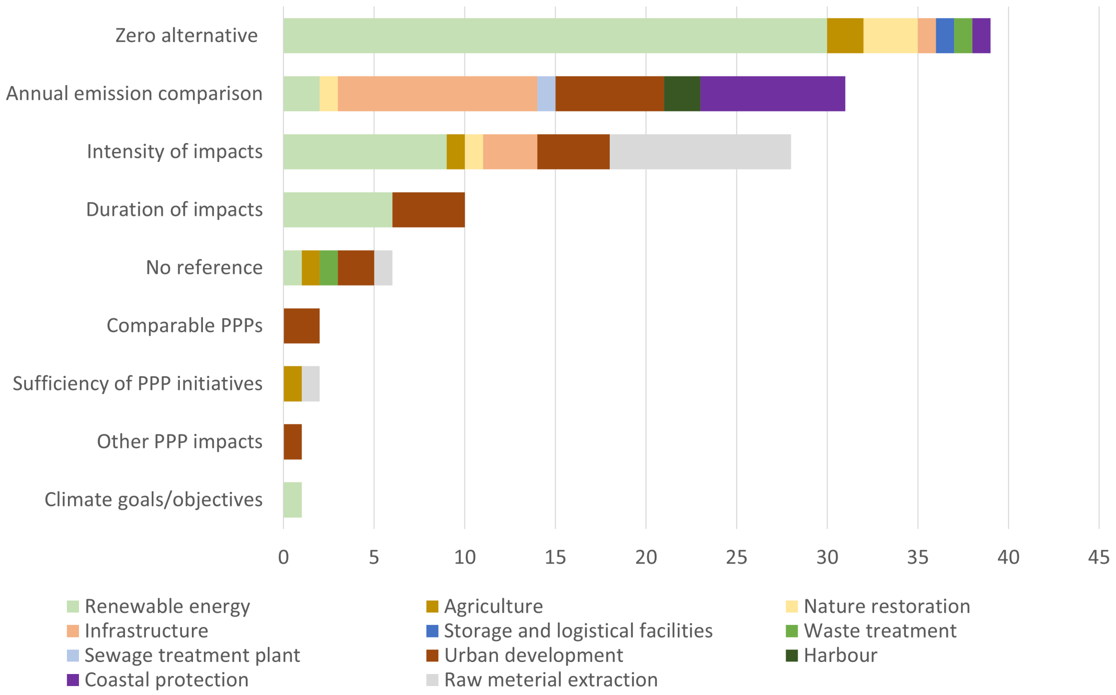


Figure 4.14. Categorisation of approaches applied for determining GHG emissions' significance, distributed according to the PPP type. (N = 120 significance quotes)

As illustrated by figure 4.13, several different categories of reference for comparison are applied in determining impact significance of GHG emissions. This indicates a lack of a systematic approach, which also correlates with the findings presented in section 2.4. Furthermore, as is illustrated by figure 4.14, some tendencies regarding the correlation between reference categories and PPP types exist. Both of these aspects are elaborated upon in the coming sections.

To further elaborate on the practice, figure 4.15 presents the distribution of determined degree of significance according to the applied reference categories.

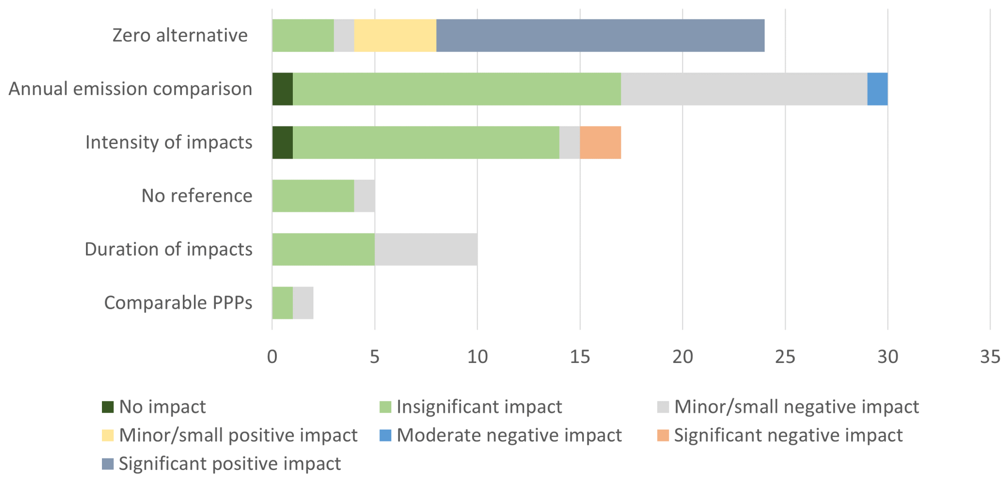


Figure 4.15. The distribution of determined degrees of significance according to the applied references for comparison. (N = 120 significance quotes)

As illustrated by the figure, the distribution of significance determinations depend on the reference category.

In table 4.1, examples are given for each reference category. It is also noted how frequently significance determination quotes have applied the reference for comparison. Finally, the table includes an evaluation of each category, in terms of whether they are considered sufficient as reference for determining the significance of GHG emission impacts. A reference category is regarded as "sufficient" if a valid approach has been used to determine significance. "Somewhat sufficient" is used for reference categories which, to some extent, are deemed valid for determining significance, while "insufficient" is used for reference categories which are not valid in determining significance.

Reference category	Example	Number of occurrences	Evaluation
Zero alternative	*"If the proposed project is not implemented (the zero alternative), the above mentioned impacts will not occur. The zero alternative will have a significant negative consequence for air and climate, as the reduction of harmful substances from implementing the project will not occur either."* (EIA: Windturbines at Ulkær moor, Urland, 2021 p. 97)	39	
	"The project's impact on the environment during the operational phase is large and positive, especially due to a large substitution of fossil fuels and thus a large reduction in CO_2 emissions from conventional power plants." (EIA: Solar energy plants at Hjolderup and Fogderup, PlanEnergi, 2020, p. 91)		
Annual emissions comparison	*"The calculation shows that the emissions from the construction work, including CO_2 emissions, are very small (0.6%) as compared to the national emissions balance, and therefore the climate impact is determined to be insignificant."* (EIA: North Sea South wind farm, Orbicon/WSP, 2020, p. 296)	31	
	"The total CO_2 emissions from the planned coastal protection amount to up to 42,500 tonnes of CO_2 equivalents, cf. "Environmental Impact Report - Coastal Protection Lodbjerg Nymindegab, 2019". Therefore, the share of CO_2 equivalents from the planned coastal protection is insignificant in relation to the total national CO_2 emissions, which in 2017 was 88,949,000 tonnes of CO_2 equivalents. The planned coastal protection therefore entails a very small climatic impact, and the consequence of the CO_2 contribution is therefore overall assessed as insignificant, as the emission contribution is minimal both at Danish and global level." (SEA: Environmental assessment of the joint agreement for coastal protection Lodbjerg - Nymindegab, Ramboll, 2020, p. 59)		
Intensity of impacts	*"Because of the new raw material extraction site, the surroundings will be impacted be increased heavy traffic to- and from the site. The impacts are significance and can only be mitigated slightly by conditions in the extraction permit, because the law on raw materials does not have authority in regulating traffic on public roads."* (SEA: Environmental report for the proposed raw material plan 2020, The Region of North Jutland, 2020, p. 28)	28	
	"During the construction of the solar energy plant, the traffic during the construction phase locally will result in a minor increase in emissions to the surroundings. The increase will be insignificant. " (EIA: Environmental assessment of proposals for municipal plan supplement NO. 10 and local plan NO. 206. Environmental impact assessment of the concrete project - Solar cells at Grænge, COWI, 2021 p. 96)		

Duration of impacts	*"Because the emission of GHG from the construction is not lasting, the impact on the surroundings, in the construction phase, is considered small."* (EIA: Environmental report for the construction of housing and parking garage, Smedeland 8A, DMR, 2020, p. 92)	10	
	"The impact in the construction phase is considered to be insignificant, as there will primarily be smaller local emissions due to increased traffic at the construction work for a limited period." (EIA: Environmental assessment of proposals for municipal plan supplement NO. 9 and local plan NO. 205. Environmental impact assessment of the concrete project - Solar park at Radsted, Guldborgsund Municipality, 2021, p. 83)		
No reference	*"It is expected that the raw material extraction will lead to an increase in CO_2 emissions locally, but overall, this will not make a difference for the climate."* (SEA: Environmental report for the proposed raw material plan 2020, The Capital Region, 2020, p. 26)	6	
	"In relation to energy consumption, it is estimated that the project will have a minor impact." (EIA: Vejland's neighborhood, SWECO, 2020, p. 132)		
Comparable PPPs	*"The indirect emissions from raw material extraction, production of building materials and waste management are therefore expected to be smaller than similar constructions in peri-urban areas. It is determined that there is a minor impact in terms of indirect emissions."* (EIA: Vejland's neighborhood, SWECO, 2020, p. 131)	2	
Sufficiency of PPP initiatives	*"It is assessed that the plan has a positive effect on climatic factors, through the allocation of raw materials for climate adaptation and through cooperation to limit the consumption of non-renewable raw materials."* (SEA: Environmental assessment for the proposed raw material plan 2020 for the South Denmark Region, South Denmark Region, 2020, p. 41)	2	
Other PPP impacts	*"Table 14-9 shows that the direct CO_2 emissions per year during the construction phase will be in the order of 34,658 tonnes. For material transport, CO_2 emissions are 1,268 tonnes. The climate impact from the construction phase constitutes a small part of the total CO_2 emissions from the project."* (EIA: Lynetteholm environmental report, Ramboll, 2020, p. 313)	1	
Climate goals/objectives	*"Aabenraa Municipality estimate that the plan proposal and the subsequent implementation of the biogas plant expansion contribute to the achievement of the municipality's climate policy and climate plan. Therefore, the reduction in CO_2 emissions has a positive effect on the environment."* (SEA: Environmental assessment of the proposed district plan nr. 134 and municipal plan amendment nr. 37 for a biogas plant on Tågholmvej, Aabenraa Municipality, 2020 p. 42)	1	

Table 4.1. Characterisation of the reference categories' sufficiency and examples of quotes related to each category. Green = Sufficient, Yellow = Somewhat sufficient, Red = Insufficient

The zero alternative

Overall, the "zero alternative" is the most frequently applied reference for comparison in determining the significance of GHG emission impacts. In total, referencing the zero alternative is applied in 39 out of 120 significance quotes. By using the zero alternative, the GHG emissions are compared to a scenario where the PPP is not implemented. For instance:

> *"The zero alternative will have a significant negative consequence for air and climate, as the reduction of harmful substances obtained from implementing the plan, will no longer apply."* (SEA: Environmental report for proposal to municipal plan amendment no. 41 and district plan no. 276 Wind turbines Ulkær Mose, Urland, 2020, p. 22)

In this example, the zero alternative is used to justify why implementing the plan would be the most climate beneficial solution. As illustrated in figure 4.14, the zero alternative reference for comparison is predominantly applied when assessing GHG emission impacts of renewable energy PPPs (30 out of 39). When compared to the zero alternative, these renewable energy PPPs rationally lead to positive effects, due to the fossil energy substitution they induce:

> *"The biogas plant contributes to the production of renewable energy, thereby reducing the use of fossil fuels and thus the CO_2 emissions. This results in a positive impact on the environment."* (EIA: Environmental report for expansion of the biogas plant Biogas Tågholm P/S, Biogas Tågholm P/S, 2020, p. 54)

Adapting the rationale demonstrated in the quote, renewable energy PPPs do not induce a need for actions to reduce GHG emissions, when compared to the zero alternative. However, for other PPP types, this is not necessarily the case, which may explain why the zero alternative is rarely applied in other contexts. As illustrated in figure 4.15, impacts are mainly determined to be significant and positive when the zero alternative is applied as reference for comparison. This correlates with the fact, that the reference is largely applied for renewable energy PPPs, as it demonstrates the GHG reduction benefits. Overall this indicates that the zero alternative is mostly applied to accentuate the positive effects of renewable energy PPPs.

As specified in table 4.1, the zero alternative is considered a sufficient reference for comparison for significance determination, because GHG emissions are compared with a realistic scenario for future developments without the PPP. Thereby, the overall effects of PPP implementation become evident. However, referencing the zero alternative lacks the potential of assessing the impacts of individual life cycle phases. Therefore there is a possibility that potentially significant life cycle phases are overlooked, especially if the overall impact from the PPP is positive.

Annual emissions comparison

A total of 31 quotes apply a reference for comparison within the category named "annual emissions comparisons". The category is consists of several different reference types, which are similar in the fact that they concern some sort of statistical figure for annual GHG emissions. The following types of references are included in the category:

Reference types	**Significance is determined**	**The impact is only characterised**
Annual municipal emissions	1	1
Annual emissions per inhabitants	4	0
Annual emissions for a specific sector/activity	8	0
Annual national emissions	17	0
Total	**30**	**1**

Table 4.2. Related reference types within the category: Annual emissions comparison.

As is presented by the table, the most well represented reference for comparison within the category is "Annual national emissions", i.e. when the GHG emissions of PPP impacts are compared to the total emissions of Denmark in a specific year. The following quote exemplifies how the reference category is applied in determining significance of GHG impacts:

> *"The annual CO_2 emissions of Denmark in 2018, were 48 million tons of CO_2 equivalents pr. year. As compared to this figure, the indirect CO_2 impact from the parking garage accounts for around 0,007% of Denmark's combined CO_2 emissions in the year 2018. (...) the CO_2 emissions in the construction phase, and from the consumed materials, are therefore considered insignificant as compared to global and regional impacts."* (EIA: Parking garage and pedestrian bridge in Vejle, Ramboll, 2020 p. 161)

The quote illustrates how the GHG emissions of a parking garage project are compared to the total annual emissions of Denmark in 2018. The results of the calculation are that the project accounts for a very small percentage of the national emissions, which leaves the impression that the impact induced by the project is negligible (and therefore insignificant).

The second most frequently occurring reference within the category is "Annual emissions for a specific sector/activity". This concerns the comparison to annual GHG emissions generated by e.g. the Danish transport sector, or total Danish emissions from road traffic or energy production. As an example:

> *"The current and future annual emissions from trucks to and from Mariager Fjord water treatment plant during the operations phase is without significance compared to the annual contribution of heavy vehicles in Denmark as a whole."* (EIA: Expansion of Mariager Fjord water treatment plant, Orbicon/WSP, 2020, p. 117)

As exemplified by this quote, the impact of the transport in the operations phase is considered insignificant compared to the total annual GHG emissions from heavy transport. In line with the comparison to annual national emissions, comparing emissions from individual PPP activities to the total emissions from this type of activity makes the impacts seem negligible.

All references for comparison within this category are regarded as insufficient in determining the significance of GHG impacts. The reason is that applying these references is seen as an attempt at articulating the magnitude of impacts in a way which makes them seem insignificant. The results presented in figure 4.15 show that the impacts, where significance is determined by comparison to this category, are almost exclusively considered as either insignificant or minor/small (negative). Logically, the amount of GHG emissions induced by individual PPPs will seem small when compared to total national-, sectoral-, or municipal emissions, or when presented in terms of person equivalents. Therefore, it could be argued that applying these reference categories has a manipulative effect on the readers comprehension of the GHG emission significance. Additionally, the reference category is mostly applied to PPP types related to infrastructure, coastal protection, and urban development (cf. figure 4.14). A commonality between these PPP types, is that they mainly have negative GHG impacts, which could explain why this reference for comparison is applied.

Intensity of impacts
The reference "Intensity of impacts" is applied in 28 quotes, thereby making it the third most applied reference. This reference category covers situations where an impact is described, and significance is determined according to whether or not it is deemed intense. In this category, intensity is considered as a scale ranking from negligible to significant. As an example:

> *"It is estimated that the annual CO_2 emissions induced by maintenance of the motorway extension are around 225 tons, including material consumption, which is considered to be a minimal annual addition of CO_2 emissions from the operations of the road extension."* (EIA: Extension of E45 Østjysk Motorway Vejle-Skanderborg, Ramboll, 2020, p. 166)

As exemplified by the quote, the significance of GHG impacts from the operations phase of the motorway, are based on the intensity of maintenance related impacts.

Figure 4.13 present that for around half of the cases where this reference for comparison is applied, the impact is only characterised, without actual determination of significance. This practise is considered to be undesirable because it leaves the reader with uncertainties regarding the significance of the impact. As illustrated in figure 4.15, impacts were this reference is applied are mostly determined as insignificant (13 out of 17 cases). This indicates that this reference primarily applied when arguing that impacts are negligible. As specified in table 4.1, intensity of impacts is considered to be an insufficient reference for significance determination, because the impacts are only determined based on the magnitude of the impact without being put into context. Furthermore, the assessment is lacking the needed transparency regarding why/why not the impact is considered to be negligible/significant.

Duration of impacts
10 quotes apply the "duration of impacts" as a reference in determining significance of impacts. The main argument is that because GHG emissions are not continuous, e.g. that they are limited to the construction phase, the impacts are not significant:

> *"The CO_2 emissions from the construction machinery and transport by truck is considered to have a small impact, but the impact temporary and brief, and is therefore not significant."* (EIA: Environmental report of housing buildings Honnørkajen, Haderslev Municipality, SWECO, 2020, p. 87)

As demonstrated by the quote, using the duration of the impact as a reference for comparison results in the impact being considered insignificant. This correlates with the results presented by figure 4.15, which indicate that impacts compared to this reference are either determined to be insignificant or minor/small (negative). As presented in table 4.1, applying this reference category is considered insufficient, as it is seen as an approach, which aims to invalidate GHG emission impacts.

No reference
"No reference" represents an approach where the determined significance is only stated, without a clear assertion of evidence. For instance:

> *"The project is not expected to have a negative impact on air or climate."* (EIA: Environmental report environmental approval according to §16a Slaughter pig production, IE use, Lemvig area farmers' association, 2020, p. 19)

As specified in table 4.1, this approach is considered insufficient. The main reason for this characterisation is that no explanation is given on what constitutes the determination of significance. This is demonstrated by the above-mentioned quote, where no particular reference is applied, i.e. there is a lack of both justification and transparency.

Comparable PPPs
In few cases (2), "comparable PPPs" is used as a reference in determining impact significance, i.e. GHG emissions of the proposed PPP are compared to those of similar PPPs:

> *"In relation to the construction, sustainability is in focus and therefore also minimizing CO_2 emissions related to material selection and suppliers. The indirect emissions from raw material extraction, production of building materials and waste management are therefore expected to be smaller than similar buildings in urban areas. The impact is considered to be insignificant."* (EIA: Environmental report of housing buildings Honnørkajen, Haderslev Municipality, SWECO, 2020, p. 87)

This quote demonstrates how similar PPPs can be used as a reference in determining significance. By using this approach, the impacts from the assessed PPP are compared to a realistic baseline for the given activity, which makes it evident how the PPP performs in relation to current practice. Overall this approach is considered to be somewhat sufficient. The reference is applicable because the impacts are put in relation to current practice which makes it clear how the assessed PPP performs. If the assessed PPP emits more than the similar PPPs, then the impact can be considered to be significant, and vice versa.

The reference is, however, also prone to potential uncertainties. One can be ascribed to the potential different system perspectives the different PPPs can have. In order to compare two different PPPs the included life cycle phases needs to be similar otherwise the comparison would be distorted in relation to reality.

Sufficiency of PPP initiatives
Two quotes apply the reference "sufficiency of PPP initiatives". When this category is used as reference the GHG emissions are compared to the initiatives undertaken to reduce GHG emission impacts of PPPs. As an example:

> *"BAT is applied to a sufficient extent to resource consumption. It has thus been explained that the specific project reduces the consumption of energy as much as possible, which all things considered, leads to smaller climate footprint from livestock farming. (. . .) Based on these acknowledgements, the specific project is not considered to cause direct or indirect impacts on land, soil, water, air, or climate."* (EIA: Environmental report for environmental application for the expansion of the pig production at Bukkeholmvej 2, 4892 Kettinge, Lemvig area farmers' association, 2020, p. 25)

As the quote indicates, initiatives implemented to reduce the GHG emissions are used to justify why the impact is considered insignificant. Overall, implementing initiatives which seek to mitigate the GHG emissions is considered beneficial. However, even though initiatives are implemented, GHG emissions can still have a significant impact, and therefore the magnitude of the impact should still be considered. This is not the case for this approach, and therefore is it considered to be an insufficient approach to determining GHG emissions significance, as specified in table 4.1.

Other PPP impacts
One quote applies the reference "other PPP impacts", which covers significance determinations where the GHG emission impact is compared to impacts from other phases or activities of the PPP. The quote is presented in table 4.1. The quote illustrates how the direct CO_2 emissions from the project's construction phase are compared to the total emissions from the project. In this case, the GHG emission impact from the construction phase is considered as accounting for a small part of the total emissions from the project. This implies that the impact induced by the construction phase is negligible even though the direct CO_2 emissions from this phase is estimated to be 34.658 tons per year. This reference category is deemed insufficient in determining the significance of GHG emission impacts, as the magnitude of impacts is articulated in a way which makes them appear insignificant. GHG emissions from one phase may still be significant even though the impact is smaller than the emissions from other project phases.

Climate goals/objectives
For this category, the determination of significance is based on the GHG emission impacts from the PPP and its effect on climate goal(s)/objective(s). Only one quote applied this reference, which is presented in table 4.1. In this case, the plans' contribution to fulfilling a municipal climate policy and -plan is applied as the reference. Because the plan concerns renewable energy (expanding a biogas plant), the GHG impacts are considered positive.

Overall, applying this reference for comparison is considered sufficient in determining the significance of GHG emissions, as climate goals/objectives can be ambitious and present a benchmark for the climate related performance. However, as exemplified by the quote, the reference can also be used qualitatively. This approach is deemed less appropriate, as it fails to clarify the specific effect of the proposed plan.

Tendencies

Based on the results, it is evident variations exist regarding the practice of determining significance in EA reports. This concerns both the explicitness of determinations, and the applied reference categories. Based on the text-analysis and following data interpretation, it can be concluded that the significance of GHG emission impacts is generally determined to some extent. However, it can be noted that significance is less frequently determined for GHG impacts assessed in SEA reports, as compared to EIA reports.

For both report types, determinations do not always include a explicit statements of the degree of significance. For the reports that do, it is evident that the majority of GHG emission impacts are considered either insignificant or minor/small. Furthermore, the impacts that are deemed significant, are almost entirely positive impacts. Overall, this indicates that GHG emission impacts rarely are considered to be significantly negative, which points to an overall passive understanding of the urgency of climate change action.

Looking into the references applied when determining the significance of GHG emission impacts, the results show that that the categories; zero alternative, annual emissions comparison, and intensity of impacts are most dominant. While the zero alternative is regarded as a sufficient reference, it should also be noted that it is primarily applied when assessing GHG emission impacts of renewable energy projects, and that the impacts are almost exclusively considered positive. The reference annual emission comparison is not regarded as a sufficient reference, as it is seen as an approach which aims at making the impacts seem negligible. This is supported by the fact that the vast majority of significance determinations, where this reference is applied, result in impacts being deemed either insignificant or minor/small negative. The intensity of impacts is also not regarded as a sufficient reference, as it fails to put the GHG impact into context, and lacks transparency in why/why not an impact is considered significance.

Overall, the identified practice is considered insufficient in terms of the transparency, consistency, and appropriateness needed to providing sound significance determinations of GHG emission impacts.

4.3 Sub-conclusion

The results of the survey illustrate that EA practitioners generally have some degree of knowledge regarding the assessment of GHG emission impacts and are acquainted with related assessment methods. Additionally, it is evident that EA practitioners have an overall negative perception of the quality of assessments, and the preciseness of methods. This correlates to the fact that the practitioners experience some degree of pressure/demand for improving the GHG emission assessment. Thus, the results from the survey indicate that the practice of assessing GHG emission is still developing.

When looking at the actual practice through text analysis of EA reports, several issues are identified:

1) **Consideration of life cycle phases is lacking from GHG emission assessments**. The majority of the analysed EA reports included only one life cycle phase in the assessment of GHG emission impacts, with the operations phase being the most predominant. This is particular valid for SEA reports, while just over half (27 out of 51) of the EIA reports include 2-4 life cycle phases. Overall, none of the EA reports included all five life cycle phases.

2) **Significance is not explicitly determined for all GHG emission assessments in EA reports**. Around 19% of the EA reports did not determine the significance of GHG emission impacts at all, while 27% of the identified quotes related to determination of significance did not state a clear degree of significance. Additionally, GHG emission impacts are mostly determined to be either insignificant or minor/small impact. Impacts are rarely determined to be significant if the impact is negative. On the contrary, impacts which are determined to be significant are almost entirely positive impacts. This indicates a practice where negative GHG emission impacts are hardly ever considered significant.

3) **The practice of determining significance of GHG emissions lacks a systematic and sufficient approach**. Several different approaches to determining the significance of GHG emission impacts were identified throughout the EA reports, while only two approaches were deemed sufficient; applying the zero alternative, or climate goals/objectives as references for comparison. 64% of the significance determinations applied a reference which was deemed insufficient, of which annual emissions comparison was the most dominant.

Overall, the results demonstrate that the practice of GHG emission assessment has several shortcomings, in regard to the inclusion of life cycle phases and the determination of significance.

5 LCT application in EA

The purpose of this chapter is to explore and present potential benefits and challenges in applying LCT for EA, and to estimate the current extent of LCA application in EA. Firstly, the topic is explored through existing research. This includes a literature review of relevant publications as well as perspectives obtained through interviews. Secondly, the practice is explored through grey literature, text analysis of EA reports, and a survey distributed to Danish EA practitioners.

5.1 Life cycle thinking

LCT is a way of understanding environmental problems and solutions throughout the entire life cycle of a product, activity or system, with the purpose of obtaining sustainable development [Thrane and Schmidt, 2007b].

According to Hauschild et al. [2018], LCT is relevant because:

> *"(...) it allows identifying and preventing the burden shifting between life cycle stages or processes that happen, if efforts for lowering environmental impacts in one process or life cycle stage unintentionally create (possibly larger) environmental impacts in other processes or life cycle stages."* [Hauschild et al., 2018, p. 12]

Thus, it is emphasised that LCT is essential since a solution to one problem may create several new problems, which are then often ignored [Hauschild et al., 2018]. LCT is based on the concept of "systems thinking", which concerns the understanding of relations and interactions between elements comprised within systems [Thrane and Schmidt, 2007b; Matthews et al., 2014]. The approach is especially relevant when dealing with complex problems, where it can difficult to foresee potential outcomes without thinking systematically.

The primary aim of environmental LCT is to reduce emissions and resource usage throughout a product's life cycle and thereby to apply broader problem solving in all of the different life cycle phases [Thrane and Schmidt, 2007b; Matthews et al., 2014]. Therefore, LCT is relevant in making informed decisions regarding environmental impacts and sustainability. However, LCT does not ensure that sustainability is obtained, as widening the understanding of sustainability can make problems seem even more complex [Matthews et al., 2014].

The typical life cycle of a product is illustrated by figure 5.1 and covers all phases from extraction of raw materials and production, to distribution and use, to reuse or disposal [Thrane and Schmidt, 2007b]. This perception is often refereed to as "cradle to grave", where the cradle represents the extraction of resources and the grave represents the end of life phase for the product. The terminology "cradle to cradle" is often used if the product is reused, remanufactured, or recycled and thereby reenters a cycle. Some life cycles can be understood based on a "cradle to gate" perception, which means the focus is on the process leading up to the point where the product leaves the factory gate [Matthews et al., 2014]. A product's life cycle can be more or less complex depending on the product. All phases have their own life cycle, for example, the machinery used to fabricate a specific component has also been manufactured, which in itself requires use of processed and extracted materials [Matthews et al., 2014].

Figure 5.1. Typical life cycle phases for a product [United Nations Environment Programme, 2022].

5.1.1 Life cycle assessment

LCA can be perceived as the main tool for implementing LCT. It can be used to consider environmental impacts from all life cycle stages and to evaluate how important the impacts are, as well as which processes the impacts are related to [Thrane and Schmidt, 2007a]. LCA is often used to study physical products, but can also be used to study more complex systems such as companies, infrastructure, or waste-, energy-, or transport management systems [Hauschild et al., 2018]. The International Organisation for Standardization (ISO) has developed global standards for LCA including ISO 14040, which addresses the principles and framework, and ISO 14044, which deals with requirements and guidelines [International Organization for Standardization, 2006a,b]. These ISO standards concern the LCA methodology, however, several other ISO standards are related to the field of LCT such as ISO 14006 addressing guidelines for incorporating ecodesign [International Organization for Standardization, 2020], and ISO 14067 related to requirements and guidelines for the quantification of product carbon footprint [International Organization for Standardization, 2018].

The main objective of LCA is to quantify environmental impacts of products and systems in order to support decisions. However, the tool has several application areas and is therefore used with varying purposes. For instance, the application of LCA can cover purposes such as: marketing i.e. eco-labelling, decision support in development of products, and selection of relevant indicators related to environmental performance [International Organization for Standardization, 2006b; Hauschild et al., 2018]. As a result, the level of detail and depth of LCA can differ depending on the objective of the specific assessment [International Organization for Standardization, 2006b].

Calculations in LCA are carried out according to a predefined functional unit and system boundary. The functional unit is the reference unit in terms of quantity, duration, and/or qualitative characteristics, while the system boundary determines the scope of the analysis - the processes taken into account [Thrane and Schmidt, 2007a]. Results of these calculations can be communicated according to several impact categories, e.g. global warming, human toxicity, eutrophication, ozone depletion, and water demand. Hereby, LCA can cover multiple environmental issues [Thrane and Schmidt, 2007a; Hauschild et al., 2018].

Many tools and concepts besides LCA are based on LCT and share some of the same objectives. This for instance applies to eco-design and circular economy [Thrane and Schmidt, 2007b; Hughes, 2017]. Thus, LCT is a widespread concept used in various contexts.

5.2 Research on LCT application in EA

This section presents findings from relevant scientific publications identified through a semi-structured literature review. In addition, these findings are supported by empirical data gathered through interviews with three LCA/EA researchers. The objective of this chapter is to obtain an overview of existing research related to the application of LCT in EA and to identify patterns and gaps in the knowledge.

The findings of the literature review are presented in table 3.4 in appendix A.1. The table presents the title of the identified scientific studies, the country in which the studies are rooted, the aim of the studies, and their conclusions. The table includes literature identified up until the 7th of February 2022 through the databases *Scopus* and *Science Direct*. A more detailed description of the literature review and the associated methodological approach is presented in section 3.3.1.

The initial search for publications related to LCT and EA indicated an inequality between the researchers' point of departure. The initial search yielded 76 publications in Scopus and 28 in Science Direct, resulting in a total of 104. However, based on the final step of the selection processes, only 16 articles were deemed relevant. The reason for this being that the majority of the studies only concerned LCA. More specifically, several articles perceived LCA as a type of "environmental impact assessment", i.e. not the formalised procedure known as EIA (as defined by Directive 2014/52/EU), which therefore meant that these articles were deemed irrelevant. Furthermore, the majority of the authors responsible for the identified scientific publications are mainly rooted in the field of LCA. Židonienė and Kruopienė [2015] are one of the exception as much of Sigita Židonienė's additional research is related to EIA. Tukker [2000] and Bidstrup [2015] also have a more EA-based background forming their research. Nonetheless, the identified publications indicate that the potential of integrating LCT in EA is primarily studied from the perspective of LCA researchers.

Out of the 16 scientific publications identified through the literature review, eight concern how LCA can contribute to EIA processes, six cover how LCA can contribute to SEA processes, and one (Bidstrup [2015]) explores the practice of applying LCT to EA in general. The last article focuses on the opposite case - how other methods, including EIA and SEA, can contribute to and broaden the LCA framework [Jeswani et al., 2010]. The research on the topic is mostly rooted in a theoretical description of the potential application and its benefits [Tukker, 2000; Finnveden et al., 2003; Jeswani et al., 2010] or in illustrations of procedures and frameworks for the application and operationalisation of LCA in EA within different case study contexts [Cornejo et al., 2005; Manuilova et al., 2009; Morero et al., 2015; Björklund, 2012; Loiseau et al., 2013; Židonienė and Kruopienė, 2015; Larrey-Lassalle et al., 2017; Madhu and Pauliuk, 2019; yu Wu and wen Ma, 2018]. However, research concerning the actual practice of applying LCT/LCA in EA processes remains scarce, as only one article touches upon this matter.

In 2000, the integration of LCA in EIA processes had been argued as a potential approach for conducting more thorough impact assessments [Tukker, 2000], and several authors have since advocated LCA as an appropriate analytical tool to be applied in both EIA and SEA practice [Finnveden et al., 2003; Manuilova et al., 2009; Björklund, 2012; Loiseau et al., 2013; Morero et al., 2015].

5.2.1 Benefits

LCA has been argued to be beneficial to various steps of the EA procedure. According to the literature, LCA can contribute with valuable perspectives in the following EA steps: design of PPP, screening, scoping, comparison of alternatives, impact analysis, determination of significance, and determination of mitigation measures. Bidstrup [2015] reviewed 85 Danish IA reports and analysed them for analytical appropriateness and application of LCT. The study concludes that some level of LCT is already included in the EA practice, but that a greater application can entail the following four main analytical gains:

1. A more explicit focus on embedded product provision.
2. A more rigorous evaluation of life cycle impacts.
3. An impact-oriented methodology for evaluating resource use.
4. A framework for quantitative comparison of alternatives.

Several of the other authors emphasise similar benefits.

Identifying hot spots

Finnveden et al. [2003] stress that a key quality of LCA in relation to SEA is that the degree of quantification is high. This notion is supported by Madhu and Pauliuk [2019] who point out that the quantitative analysis provided by LCA makes it possible for project developers to make more informed decisions. Several authors highlight the ability to identify hot spots as a significant analytical gain in this regard, as it helps to pin point the main environmental impacts [Madhu and Pauliuk, 2019; Židonienė and Kruopienė, 2015; Loiseau et al., 2013; Larrey-Lassalle et al., 2017]. Larrey-Lassalle et al. [2017] suggest that this can bring value to the scoping phase by identifying main environmental concerns.

Defining scope

Several authors agree that LCA can contribute to more rigorous evaluations of life cycle impacts [Manuilova et al., 2009; Židonienė and Kruopienė, 2015; Larrey-Lassalle et al., 2017; Madhu and Pauliuk, 2019]. In this regard, Larrey-Lassalle et al. [2017] emphasise that the LCIA results enable consideration of a wide range of impact categories, such as climate change, human health, resource depletion and more, thereby making LCA relevant for predicting many different environmental impacts. Židonienė and Kruopienė [2015] stress that LCA enhances the procedure of EIA as it extends the assessment boundaries and gives a broader scope of the environmental assessment. Madhu and Pauliuk [2019] support this notion and describe that LCA can widen the scope of the impact assessment as it quantitatively evaluates the environmental impacts related to the life cycle of a project. Additionally, Manuilova et al. [2009] point out that LCA enables the inclusion of both up- and downstream life cycle stages, which are otherwise not often included in EIA. Madhu and Pauliuk [2019] emphasise that EIA often do not address the demolition phase, why LCA can contribute to steering the project in a more sustainable direction. Contrary to this notion, Bidstrup [2015] found that downstream impacts are considered in many EAs but that the inclusion of upstream, distant impacts were more scarce. The inclusion of up- and downstream impacts are advocated for by several authors as an analytical benefit of applying LCA in SEA and EIA [Tukker, 2000; Finnveden et al., 2003; Manuilova et al., 2009; Björklund, 2012; Rybaczewska-Blażejowska and Palekhov, 2018]. In addition Rybaczewska-Blażejowska and Palekhov [2018] emphasise that LCA can contribute to identifying both direct, indirect and cumulative impacts.

Comparison of alternatives

Furthermore, it is widely recognised that LCA can be used to compare alternatives [Tukker, 2000; Cornejo et al., 2005; Manuilova et al., 2009; Morero et al., 2015; Židonienė and Kruopienė, 2015; Bidstrup, 2015]. Tukker [2000] concludes that LCA can benefit the EIA process, mainly in relation to questions of alternatives, and according to Židonienė and Kruopienė [2015] LCA and EIA integration provides more detailed and relevant information in the selection of alternatives. [Manuilova et al., 2009, p.4517] state that *"the EIA procedure can never be complete without using elements of the LCA methodology"* and explains that it is not possible to evaluate and test all the alternatives extensively/comprehensively without LCA. While the EIA is specific to a project, LCA comprehensively compares similar alternatives and takes into account all important aspects. Furthermore, using LCA methodology as the basis for EIA allows for a more complete evaluation of environmental impacts [Morero et al., 2015]. Rybaczewska-Blażejowska and Palekhov [2018] add to this notion by emphasising that LCA can provide quantitative data about potential impacts including the magnitude or scale for each alternative, which can help identifying the best option. This statement is supported by the findings by Larrey-Lassalle et al. [2017] where a LCA methodology was applied to two water treatment plants that had already undergone EIA. The aim was to compare results of the assessments with and without LCA, and showed that less polluting technologies could have been chosen through use of LCA.

System perspective
LCA has a wide systems perspective, enables considerations of the environmental impacts of products in a cradle-to-cradle perspective. By considering the entire life cycle of PPPs, LCA may increase the level of detail and accuracy of EA, thereby validating the results of the impact assessment [Manuilova et al., 2009]. In this regard it is argued by Rybaczewska-Blażejowska and Palekhov [2018] that an EIA-LCA integration will increase the credibility and reduce uncertainties of the assessment, which is considered to entail more accurate significance assessments. However, modelling choices are important in this regard, since an LCA can be conducted with only a few life cycle phases and activities. Therefore, it can be argued that LCA can also be used to presented the preferred results, e.g. choice of only presenting insignificant life cycle phases. In this regard, it is important to specify that LCA can also reduce the credibility in cases where applied datasets are uncertain. In an interview with Morten Bidstrup Ramshev, he mentions *"Is it not better to assess the climatic impact qualitatively, if you dealing with a plan with such a high degree of uncertainty that it does not make sense to do the calculations? [...] The LCA is not better then the data you apply"* [Ramshev, 2022]. By this notion, Bidstrup emphasises that it is important to reflect on the datasets applied in the assessment, and in some cases consider if qualitative assessments would be a better approach.

Mitigation
Mitigation measures are incorporated in EA with the purpose of accommodating significant impacts, however they may themselves entail negative impacts when being implemented. Larrey-Lassalle et al. [2017] argue that LCA can be applied in this context to shed light on these potential associated negative impacts, which will act as useful information when determining mitigation measures.

5.2.2 Limitations

As highlighted in the previous sections, various authors have promoted the integration of LCA in EA practice and have highlighted several benefits of doing so. However, previous studies and the interviewees have also brought to light the challenges and limitations of these integrated approaches. Overall, the limitations presented in the literature and by the interviewees can be divided into three categories: the role of the EA practitioner, the required resources, and methodological differences.

The EA practitioner
EA and LCA vary in terms of focus. Generally speaking, LCA has a product-oriented/systems focus, while EA is more focused on the specific PPP in question. [Bidstup et al., 2015, p.143] argue that changing this "assessment paradigm" may pose a challenge for spatial planners. Furthermore, the ability to conduct integrated assessments also implies that practitioners have the required expertise and skills within both EA and LCA [Larrey-Lassalle et al., 2017; Židonienė and Kruopienė, 2015]. Ramshev [2022] raises similar concerns, however he also implies that EA practitioners do not need to be LCA experts in order to understand the advantages of applying the tool. He specifies *"Most EA practitioners are versatile experts, they have little knowledge in many areas [...] I think we need to define [red. among EA practitioners] what a significant climate impact is, which should therefore be included in an EA, and after that we need LCA professionals to deliver a product"*. Hereby, Ramshev [2022] states that EA practitioners do not necessarily have

to be able to perform LCA. According to Björklund [2022], EA practitioners should as minimum have knowledge about LCT and the whole PPP systems perspective in order to grasp the magnitude of the GHG emissions impact.

The question of subjectivity in presenting LCA results is also relevant, as developers may want to highlight certain impact categories [Židonienė and Kruopienė, 2015].

Required resources
Several articles present the additional resources required to conduct LCA as a limitation in integrating the tool in EA processes [Rybaczewska-Błażejowska and Palekhov, 2018; Larrey-Lassalle et al., 2017; Finnveden et al., 2003; Madhu and Pauliuk, 2019; Židonienė and Kruopienė, 2015; Bidstrup, 2015]. Conducting LCA is a time consuming task, as it involves modelling considerations, and requires additional data collection and processing. Furthermore, the possibility that an EA includes assessment and comparison of several alternatives means that multiple LCAs may be required [Rybaczewska-Błażejowska and Palekhov, 2018]. Integrating the tool would therefore prolong the time span of already time-intensive EA processes. Consequently, the use of LCA would also increase the costs of assessments, which may be an obstacle in promoting the tool for EA-purposes [Rybaczewska-Błażejowska and Palekhov, 2018; Larrey-Lassalle et al., 2017; Bidstrup, 2015]. Larrey-Lassalle et al. [2017] estimate that the additional costs of performing a comprehensive LCA would potentially double the price of EIA studies.

In this relation, [Bidstrup, 2015, p.78] argues that LCA should not be applied *"where the gain is minimal or where tool application represents an unreasonable increase in costs."*. Another approach to overcoming the obstacles of resource intensity were suggested in an interview with LCA researcher Pyrène Larrey-Lassalle. She elaborated on the findings of her study, which demonstrated that simplified LCA tools could be used in order to save time and expenses [Larrey-Lassalle, 2022]. This notion is supported by Ramshev [2022] *"I think, it is important to articulate that average value datasets are okay to use"*. Thus, both researchers support the possibility of using simplified datasets in order to save resources.

Methodological differences
Another issue in combining EA and LCA approaches is that they vary in terms of scope (system boundaries). With some exceptions, EA primarily has a local focus. EIA in particular is often limited to on-site impacts under different scenarios [Larrey-Lassalle et al., 2017]. However, the EIA directive states that the vulnerability within geographical areas that are affected by projects must be taken into account [The European Union, 2011]. Thus, impacts which exceed the geographical extent of the project site must also be taken into account.

The scope of LCA on the other hand does not make the distinction between the different geographies of impacts [Larrey-Lassalle et al., 2017; Björklund, 2012]. Therefore, some authors also argue that relying too heavily on LCA may be an issue. It is argued by Loiseau et al. [2012] that characterisation of site-specific impacts in LCA is still in development. Furthermore, both Larrey-Lassalle et al. [2017] and Loiseau et al. [2012] argue that LCA methods lack consideration of certain environmental issues. This is supported by the findings of Björklund [2012] and Jeswani et al. [2010], concluding that LCA is insufficient in addressing all aspects of environmental impacts and must therefore be complemented by other tools and methods.

5.2.3 Comparison of tools

Table 5.1 presents an overview of the main characteristics for LCA and EIA/SEA based on finding from the literature review.

	LCA	**EIA/SEA**
Objective	To evaluate environmental performance of a product, process or service and identify possible improvements from a life cycle perspective	To ensure a high level of environmental protection through considerations of environmental concerns during the preparation and adoption of PPPs, and that the public is included as early as possible.
Type of tool	Analytical	Procedural
Main use	To identify and communicate opportunities for improving the environmental performance of products, thus informing decision-makers in regards to planning, prioritisation, or design	To identify significant impacts and propose mitigation measures, thus ensuring that proposed developments meet the legislative requirements of environmental authorities
System boundary	Global and regional impacts throughout the life cycle	Local, regional and global impacts of a PPP (though with emphasis on local)
Time	Retrospective and prospective (theoretically)	Prospective
Spatial focus	Typically, not site-specific	Site-specific
Definition of environment	Biophysical factors (e.g. Global warming, ozone depletion, acidification, eutrophication, toxicity)	Biophysical-, social-, and socio-economic factors
Strengths	Systematic assessment of the environmental impacts of product systems High degree of quantification Rigorous evaluations of life cycle impacts	Legal requirement Broad environmental focus Proactive Considers cumulative effects Involves the public
Weaknesses	Does not typically address the economic or social aspects of a product (however, practices are developing) Data can be difficult to obtain, and assessments can be time consuming and costly*	Boundaries limited to a proposed PPP No consistent methodology to assess impacts Cannot easily address global and regional effects along the life cycle

Table 5.1. Comparison of LCA and EIA/SEA. Inspired by Manuilova et al. [2009]. (*Recent developments have, however, had an impact on these aspects. As an example, authorities are implementing simple LCA-based calculators such as "the Climate Compass" [The Danish Business Authority, 2022] and LCAbyg [BUILD and Aalborg University, 2022])

5.3 The practice of LCA application in EA

This section aims to present the current practice of LCA application for GHG emission assessment, which is explored by the means of several methods. Firstly, grey literature including formal documents from academic institutions and government agencies that concern LCA application for EA. Secondly, the topic is explored through a survey, in which Danish EA practitioners have been asked about their knowledge and experience regarding LCT and LCA. Finally, a text analyses has been conducted with the goal of identifying recent EA reports that include GHG emissions assessment, life cycle perspectives, and LCA application.

5.3.1 Grey literature

Grey literature covers guidance documents from academic institutions and government agencies and is included to get an overview of how widespread the concept of LCT/LCA application in EA processes is in official documents. The purpose with many of the guidance documents is to contribute with suggestions for improvement to the current EA practice. Because of that, perspectives from grey literature are also included in order to obtain knowledge about where the current development is moving towards.

Even though several scientific studies acknowledge the benefits of integrating LCA in varies EA steps, neither the EU guidance documents regarding screening and scoping, nor the better practice guide for SEA touch upon this matter [The European Union, 2017c,b; do Rosário Partidário, 2012]. However, the EU guidance on the preparation of the Environmental Impact Assessment Report mentions that LCA can be used to consider the overall direct and indirect balance of GHG emissions of a project, or to assess the use of natural resources in EIA The European Union [2017a]. Furthermore, the guidance document emphasise that LCA is particularly useful in integrating climate change considerations in EIA. LCA is especially relevant during the impact assessment stage of EIA as it can provide information on alternatives by identifying the most significant elements of a project The European Union [2017a]. However, according to the SEA guidance on climate change and biodiversity assessment *"LCA is more likely to be relevant for providing a way of thinking about strategic options rather than being applied more formally"* [The European Union, 2013b, p.66]. Thus it is proposed that LCT could also be applied as a more overall understanding, rather than applying LCA calculations. Both the IAIA best practice guide on climate change in impact assessment and IEMA's guide on assessing GHG emissions emphasise that a life cycle approach should be used to calculate GHG emissions in EA [IAIA, 2018; IEMA, 2022]. However, common to all the official documents is that they do not provide detailed information on how to apply LCT or LCA in EA, but highlight it is a potential procedure and point to some of the same advantages as the scientific studies.

5.3.2 LCA experience of Danish EA practitioners

A survey has been conducted in order to investigate Danish EA practitioners' level of experience regarding LCA application. A thorough description of the applied survey method can be found in methodology chapter, section 3.3.2.

The first question that the respondents were asked to answer was to define their degree of knowledge regarding the LCA tool. The responses appertaining to this question are presented in figures 5.2 and 5.3.

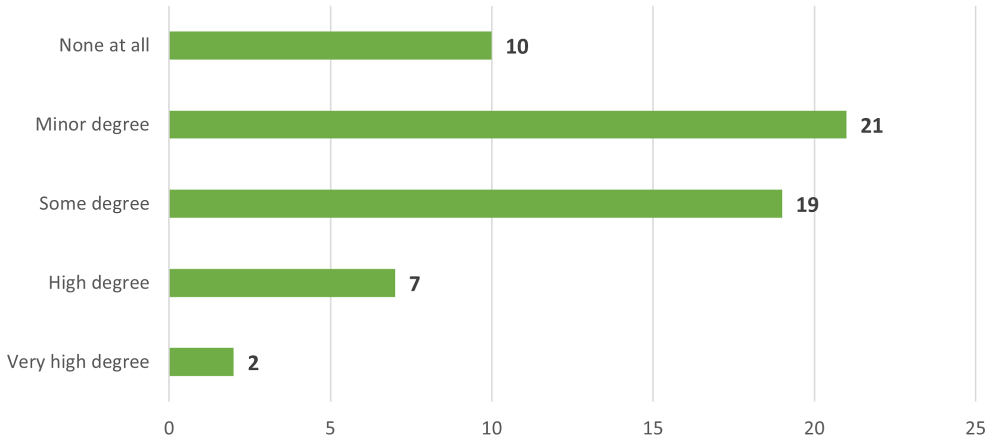


Figure 5.2. Distribution of responses regarding the respondents' degree of knowledge of the LCA tool.

As illustrated by figure 5.2, the majority of respondents perceived their level of knowledge as low or limited ("minor degree" and "to some degree"), while only 9 (15%) replied that they had a high or very high level of knowledge in this regard. Moreover, 10 of the respondents (17%) replied that they have no knowledge at all of the LCA tool. Thereby, it seems that practitioners generally have limited knowledge of the tool. When looking at the distribution of replies according to the respondents' employment (figure 5.3), it is clear that the respondents' knowledge of LCA vary somewhat according to their employments.

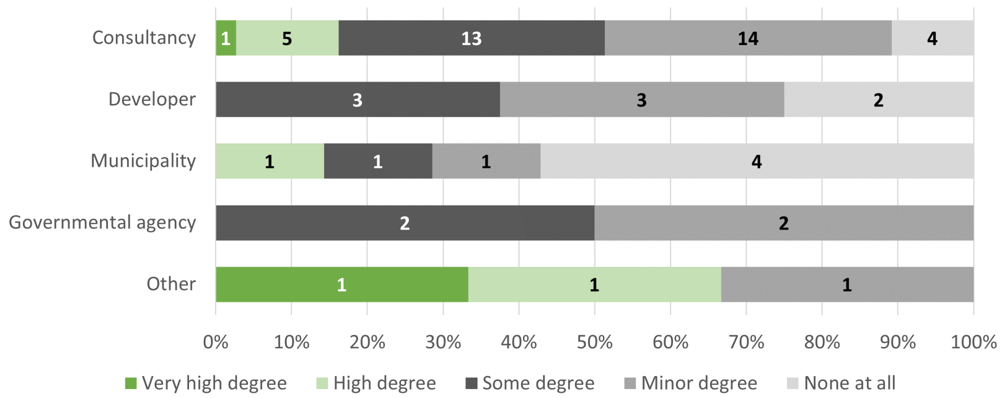


Figure 5.3. Distribution of respondents according to their employer and their knowledge of the LCA tool

The distribution shows that practitioners employed at consultancies (and "other": student, freelancer, EU institution) are more acquainted with LCA compared to the remaining groups. Approximately, 16 % of the practitioners within consultancies and 66 % of practitioners employed other places have a high or very high level of knowledge of the tool. Meanwhile, over half of the respondents employed by a municipality (4 out of 7) replied that they have none knowledge at all of the tool, and none of the practitioners employed by developers or governmental agencies have a high or very high level of knowledge in this regard.

These results align with the replies regarding the respondents' experience with applying the LCA tool in assessing impacts of GHG emissions related to a specific PPP, and the degree of which they experience that LCA in general is applied as a tool in assessing impacts of GHG emissions:

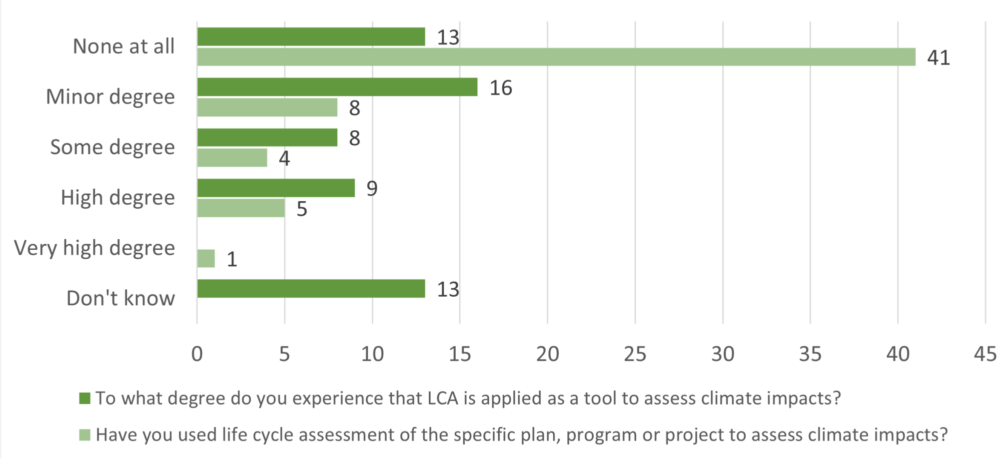


Figure 5.4. Distribution of respondents regarding the respondents' experience with applying the LCA tool in assessments of GHG emissions impacts related to a PPP, and the degree of which they experience that LCA in general is applied as a tool in assessing impacts of GHG emissions.

As presented by figure 5.4, the vast majority (70%) replied that they had not applied LCA at all. This corresponds to the respondents' replies regarding the degree of which they experience that LCA is applied as a tool in assessing impacts of GHG emissions. While 22% replied that they did not know, 49% replied that the tool is applied to a minor extent or not at all, and 29% replied that it is applied to some or great extent. Overall, this indicates that the average EA practitioner lacks knowledge of LCA in general, as well as experience within application for impact assessment of GHG emissions.

The following question concerned the degree to which the respondents saw a need to make assessments of GHG emissions more data driven. The distribution of responses is presented in figure 5.5.

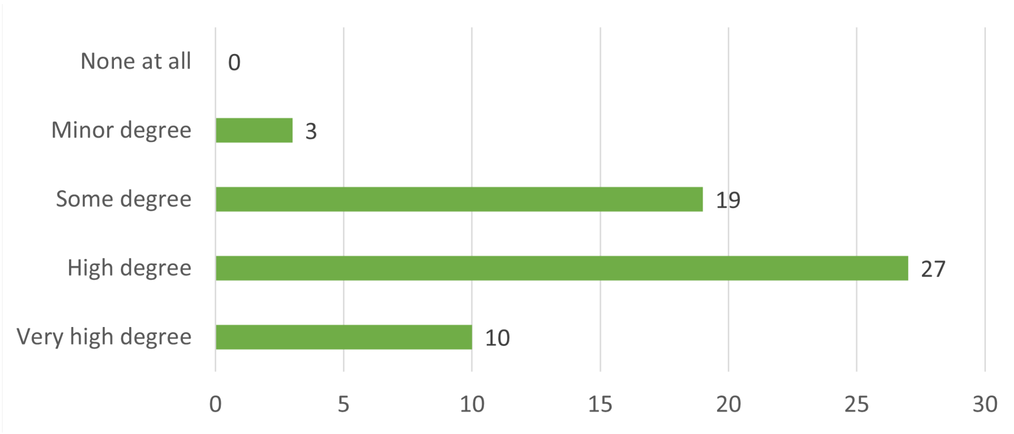


Figure 5.5. Distribution of responses regarding the respondents' perception of a need for more data driven assessments of GHG emission impacts.

The vast majority (63%) replied that they either highly or very highly did so, while 32% did so to some degree. Only three respondents replied that they saw a minor, while none of the respondents replied that they saw no need at all. It is unsure why practitioners see a need for more data driven assessments of GHG emissions, though it may relate to the findings in chapter 4, figure 4.4, which shows that the majority of respondents perceived the quality of GHG emission assessments as either medium or poor. More data driven assessments may be perceived as a mean to obtain greater quality.

In regard to the perception of a need for more data driven assessments, the final question was whether the respondents had experienced pressure and/or demand for incorporating life cycle perspectives in impact assessments of GHG emissions. The replies are presented in figure 5.6.

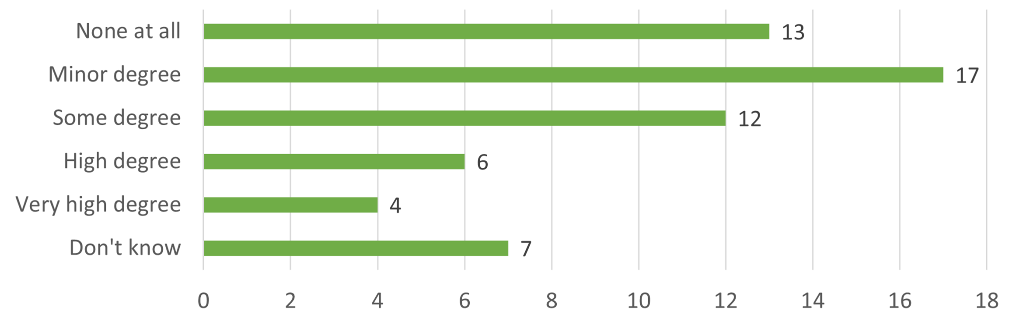


Figure 5.6. Distribution of responses regarding the respondents' experience of pressure/demand for applying life cycle perspectives in impact assessment of GHG emissions.

Contrary to the general perception that more data driven assessments are needed, over half of the respondents (51%) replied that they had either experienced a minor degree of pressure/demand, or none at all. 20% had experienced some pressure/demand, while 17% had experienced a high or very high level of pressure. Overall, this shows a low pressure/demand for incorporating life cycle perspectives in impact assessments of GHG emissions.

Based on the survey results, it is evident that practitioners lack knowledge of LCA as a tool and experience of applying it. However, there seems to be a perception among EA practitioners that LCA (or other data driven tools), can and should be applied for GHG emission assessments. Although, the lack of pressure/demand may indicate that the approaches to LCA application, as well as the benefits hereof, are not clearly demonstrated or known.

5.3.3 LCT and LCA application in Danish EA reports

In order to investigate the current state of LCT and LCA application in EA practice, a text-analysis of Danish EIA and SEA reports has been conducted. A total of 762 reports, published within the period 2017-2021, were identified through the DREAMS database. The reports have been prepared by various different authors, including municipalities, consultants, and government agencies, and vary in terms of PPP types. The aim of the analysis was to; a) identify the number of reports that include impact assessment of GHG emissions, b) present the proportion of reports where impact assessments (of GHG emissions) include life cycle perspectives, c) present the proportion of reports were LCA has been actively applied as a tool in assessing the impact of GHG emissions. The findings are presented in the pie chart below.

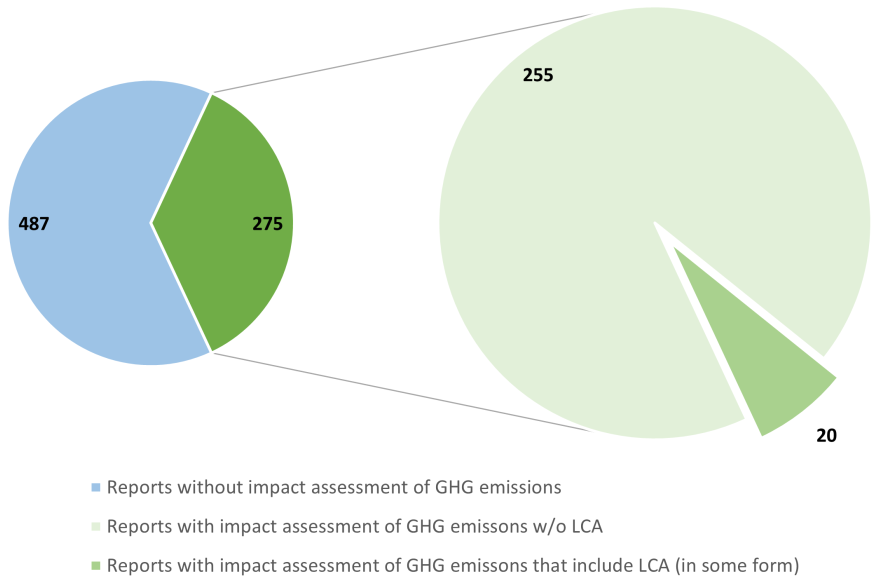


Figure 5.7. Recent Danish EA reports that include impact assessment of GHG emissions, and the proportion that either include life cycle perspectives and/or apply LCA as an assessment tool.

As presented by the chart, just over a third of the reports included assessments of the GHG emissions impacts. The general tendency is that LCA is rarely applied in impact assessment of GHG emissions. More specifically, only 20 (5,45 %) of the reports include LCA in some form.

When looking into the reports that do in fact include life cycle perspectives in assessing GHG emission impacts, the utilisation can be divided into the three categories presented by figure 5.8. Category 1) includes reports that reference findings of existing LCA studies, i.e. studies that are not purposely conducted in relation to the specific EA. A reoccurring example of this, is referencing general LCA studies of wind turbines in order to argue the positive environmental impact over time. Category 2) includes reports, where data from LCA databases is applied to e.g. estimate CO_2-emissions from the applied materials. This practice is not considered as LCA, because it only concerns selected parts of the product system. Category 3) includes reports where LCA is actively applied as an impact assessment tool. Reports within this category differ from those in category 2), as they explicitly state that LCA modelling has been conducted.

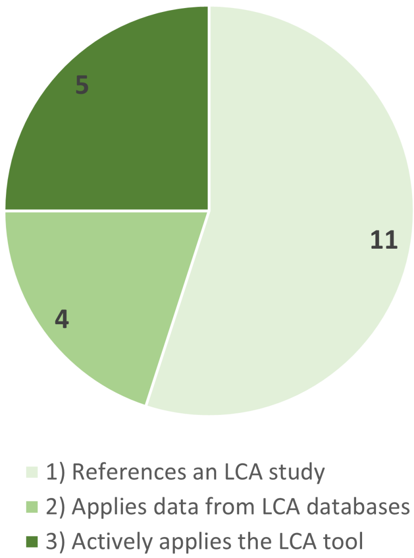


Figure 5.8. Categorisation of how life cycle perspectives are applied in impact assessment of GHG emissions.

As presented by the figure, referencing existing LCA studies (category 1) is identified as the most predominant application of LCA. This correlates with the notion that this approach is the least labor intensive, as it does not require any modelling considerations. It is, however, also the most generalised approach, as it does not take the specific characteristics of the PPP into account.

To further elaborate upon the practice, additional characteristics of the reports that include life cycle perspectives are presented by figure 5.9. The figure illustrates the distribution of the categories presented by figure 5.8, according to the PPP type.

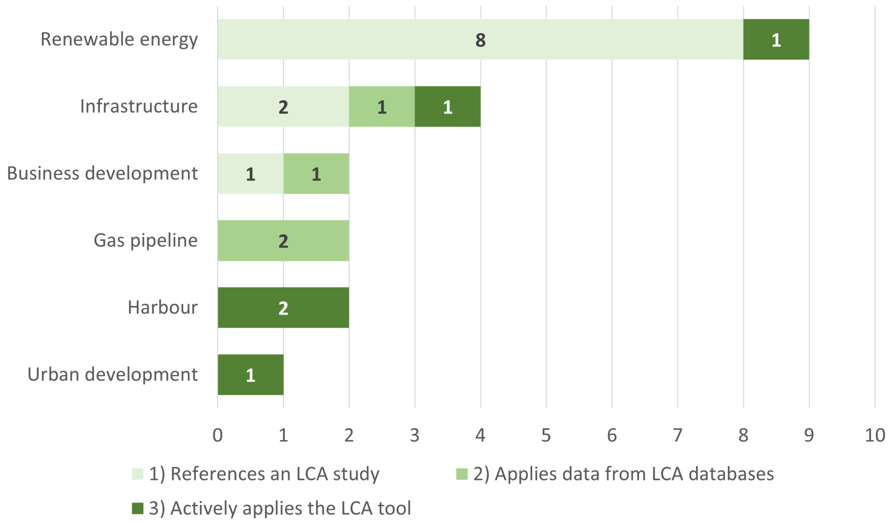


Figure 5.9. The distribution of reports according to the PPP type.

As is illustrated by figure 5.9, renewable energy is the most predominant category overall, as almost half of the identified EA reports concern renewable energy projects. This correlates with the aforementioned reoccurring reference to general LCA studies of wind turbines. However, harbour projects are most predominant in for the assessments where the LCA tool has been actively applied.

Another noteworthy fact is that all of the identified reports are EIAs, indicating that LCA is primarily applied in assessing impacts of projects.

An overview of the five reports where the LCA tool was actively applied in assessing GHG emission impacts is presented in table 5.2. The table includes information related to the type of report, the year of publication, the author of the report, software and data sources applied, the life cycle phases included, and the determination of significance.

Overall, these examples of LCA application in EA illustrate a lack of transparency. None of the reports include a thorough description of modelling approaches, i.e. choice of functional unit, system boundaries, or assumptions. Thus, it is difficult to comment upon the application of the method. Furthermore, it is difficult to determine whether LCA is applied in assessing all of the life cycle phases listed in the table. Therefore, it should be noted that the listed phases are the those which are included in the assessment overall. Despite of the claim that LCA is applied, the life cycle phase 'demolition and waste processing' is excluded from all of the assessments without any justification. While this phase may be deemed irrelevant by the authors, the lack of justification indicates that impacts have potentially been overlooked. It is evident that different software and data sources are applied for LCA modelling, indicating a lack of a consistent LCA approach. Furthermore, the determined significance is aligned with the results presented in chapter 4, section 4.2.2. When the impacts are negative, they are either considered insignificant or minor/small.

Report name	Type of report	Year	Author	Software and data sources	Life cycle phases	Determination of significance
The third Limfjord crossing update of EIA for the Egholm connection - EIA report	EIA	2021	Ramboll	Software: VejLCA*	Extraction of raw materials Production of materials Transport of materials Construction	Minor/small (negative)
					Operation	Minor/small (negative)
Sub-report 1 - Esbjerg Port Stage 5	EIA	2020	NIRAS	Software: SimaPro Database: EcoInvent	Extraction of raw materials Production of materials Transport of materials Construction	Insignificant
					Operation	Minor/small (negative)
New biorefinery at Vordingborg Harbour, Masnedø	EIA	2018	Biofuels Vordingborg A/S	Life cycle inventories EcoInvent database Literature	Production of materials Construction	Insignificant
					Operation	Insignificant
					Life cycle*	Large and positive
Expansion of Grenaa Port	EIA	2017	NIRAS	Software: SimaPro Database: EcoInvent, Forwast, European Life Cycle Database	Production of materials Transport of materials Construction	No determination of significance
					Operation	Positive
Environmental impact assessment and environmental report for the expansion of Fisketorvet	EIA	2017	MOE	Emission factors from: 1) Previous studies 2) 'Klimakompasset' 3) The Danish Ministry of Transport's model for emission calculations for Transport	Production of materials Transport of materials Construction	Insignificant
					Operation	Insignificant

Table 5.2. Overview of the 5 reports actively applying LCA, including the type, year, and author of the reports as well as the methodology applied, the life cycle phases included and the determination of significance related to each phase. Blue = qualitative assessment, Green = quantitative assessment. (*The life cycle of the project's bio-oil)

5.4 Sub-conclusion

Based on the results presented in sections 5.2 and 5.3, several conclusions can be drawn. The findings of the literature review present that several benefits of applying LCT for EA purposes exist. These include the ability to; identify environmental hot spots, broaden the scope of assessments e.g. through incorporating up- and downstream impacts, and quantitatively compare alternatives. However, several articles also emphasise limitations, mainly in relation to required resources, and the competences of practitioners.

The review has also shown that limited research has been done on the topic. A total of 16 relevant articles published within the last 22 years were identified. As is also emphasised by Madhu and Pauliuk [2019], there is an overall lack of studies exploring the practical application of LCT/LCA, as well as how the approach could become part of EA practice. While the identified articles vary in terms of focus, e.g. different sectors, cases and assessment types (EIA/SEA), it could be argued that there is a need to strengthen existing knowledge within the field. In this regard, Rybaczewska-Blażejowska and Palekhov [2018] suggest that further research on different project types and variants of LCA analysis are relevant. Finnveden et al. [2003] and Madhu and Pauliuk [2019] support the perspective that there is a potential to diversify the findings through other methodological approaches and cases.

Several of the identified publications had a practical approach to the research, i.e. there was a predominant focus on the benefits of applying the LCA tool. This indicates a "push" from researches towards a higher degree of LCA application within EA processes (which also correlates with the fact that the majority of authors have a background in predominantly LCA research). However, when looking into the practice of LCA application in EA, it could be argued that this is quite contradictory to the research. As demonstrated, only 20 recent EA reports applied LCA in any extent, while only five applied it "actively". Furthermore, these examples indicate a lack of transparency in regards to the LCA approach, and neglect to include all life cycle phases. The survey results indicate that while just under half of the respondents have a moderate to high level of knowledge regarding the LCA tool, only few had actual experience in applying the tool for EA. In addition, the only article identified as focusing on the practice of applying LCT for EA, concluded that it is rarely applied beyond renewable energy projects [Bidstrup, 2015]. This tendency is also supported by Larrey-Lassalle [2022] who confirms that *"I think for the moment it [red. LCA] is not integrated into the practice of environmental assessments"*. Overall, these perspectives indicate a lack of corresponding "pull" from EA practitioners.

6 LCT as an integrated part of the EA process

The aim of this chapter is to explore the potentials of applying LCT when assessing GHG emission impacts in EA, and thereby answering sub-question 3. The chapter builds upon the findings of the previous chapters regarding the assessments of GHG emissions. Two EA reports are selected as cases, with focus on the GHG emissions assessments' inclusion of life cycle phases and significance determinations. This is done in order to demonstrate how LCT may be applied, and how it may contribute to improving the assessment of GHG emissions.

The analysis includes illustration of how LCT can contribute to identifying all conceivable life cycle phases for each PPP, as well as a simple modelling of the two systems using LCA software (LCA screening). These efforts are aimed specifically at demonstrating the benefits of LCT application in the screening and scoping phase of EA, an should be perceived as an experiment, where the authors of this thesis assume the role of EA practitioners. Thus, the conclusions of this section will reflect the experiences gained through applying LCT to these specific cases.

Having demonstrated the application of LCT, the focus of the chapter shifts to significance determination. It is discussed how LCT can contribute to determining significance of GHG emission impacts. Furthermore, a solution to the issues identified in the previous analysis is proposed.

6.1 Inclusion of life cycle phases

As has been demonstrated by the findings presented in chapter 4 (section 4.2), Danish EA reports generally lack life cycle perspectives in assessments of GHG emission impacts. This is indicated by the fact that the majority of analysed EA reports included just one life cycle phase in this regard. Furthermore, the practice is not in line with the EU directives and guidelines, where it is stated that environmental assessment of projects should include GHG emissions over the entire life cycle [The European Union, 2017a]. The practice indicates a lack of attention to the interrelations between different activities throughout the life cycle of a proposed development. As an example, the construction of a bridge will requires specific materials, e.g. steel, which is comprised of iron ore and other minerals that are mined from the earth. Thus, an assessment which only takes into account the impacts from constructing the bridge, thereby disregarding the induced impacts from mining-, producing-, and transporting steel, may lead to wrongful conclusions. The same can also be said for developments that have a positive impact on GHG emissions during the use phase (e.g. windturbines), which may balance out or even surpass the negative impacts from production, construction, and maintenance.

As explained in section 5.1, LCT is an approach to comprehending environmental consequences throughout the life cycle of a product, activity or system. The objective is to gain a holistic understanding of the system, as well as the interrelations between the elements within. In this regard, LCT is proposed as an approach to ensure that potentially relevant environmental aspects throughout all life cycle phases of the proposed development are considered. In order to explore the potentials of LCT in EA, two cases have been chosen based on the criteria presented in section 3.3.5. The cases are examples of GHG emission assessments in EIA reports, and are selected as a means of demonstrating how LCT can be applied in an EA context. The analysis includes simple LCA modelling of both systems. Before the analysis is initiated, the LCA approach is presented.

6.1.1 LCA approach

In this section, the applied approach applied for the LCA of the two chosen cases is explained. This includes a description of the applied database, software, functional units, system boundaries, and calculation method. A description of data inventory and assumptions are included for each system, and can be found in the respective sections (6.1.2 and 6.1.3).

Database and software
The background data sets applied in both LCAs derive from the database Ecoinvent 3 - consequential - unit (Ecoinvent 3.6). Thus, the assessments are made according to the consequential approach. This entails including activities in the product system, when and if these are expected to be influenced as a consequence of changing demand [Consequential-LCA, 2021]. The LCA calculations were made by use of the software SimaPro. SimaPro is a leading LCA software, which allows the user to model and analyze complex life cycles in a systematic and transparent way [PRé Sustainability, 2020].

Goal
The goal of both studies is to demonstrate how LCA can contribute to identifying life cycle phases and activities that are potentially relevant in regards to the GHG emissions impact. In LCA terms, the procedure of investigating which activities/phases are most significant within different impact categories is commonly referred to as "hotspot analysis". It is assumed that this procedure can contribute to the scoping phase in EA, and therefore, the goal is not to create LCA models that are exact representations of reality. Instead, the aim is to demonstrate how fairly simple (and less time consuming) modelling can be utilised EA practice.

Functional units
In LCA modelling, the functional unit (FU) acts as a quantified reference to which inputs and outputs are normalised[1]. The FU should be in alignment with the goal and scope of the assessment, and clearly represent the function of the system [International Organization for Standardization, 2006b]. The purpose of the LCA calculations conducted in this study, is to provide an overview of GHG emission hot-spots. Therefore, the selected FUs represent the function of the specific systems, instead of units that would allow for comparison with other systems.

[1] mathematically, i.e. the scaling of data

For the road project, the chosen functional unit is: *1 km of road with a life time of 22 years.* Thus, inputs and outputs are normalised according to the amounts required for the existence of 1 km of the road.

For the wastewater treatment plant, the chosen functional unit is: *5.400.000 m^3 of treated wastewater*, which is equivalent to the increased treatment capacity from expanding the plant, over a period of one year. Similarly, the inputs and outputs are normalised according to the amounts required for the treatment of 5.400.000 m^3 of wastewater.

System boundaries
The approach to both assessments is to include all conceivable life cycle phases and related activities (illustrated by figures 6.1 and 6.4). Therefore, the calculations represent a cradle-to-cradle approach, extending from the extraction of raw materials through to demolition and waste processing, including the recycling of materials for use in other product systems. However, due to data gaps, it was not possible to include all the listed activities, and the system boundaries were therefore based on the availability of data.

Calculation method
The chosen SimaPro calculation method is "IPCC 2013 GWP 100a". The method is developed by the Intergovernmental Panel on Climate Change, and contains the climate change factors of IPCC with a time frame of 100 years. It presents results in the unit kg CO_2 eq, and does not include normalization or weighting options.

6.1.2 Case 1: Road upgrade project

The assessment of GHG emissions in the EIA report "Upgrading of E55 (Nykøbing Falster - Sydmotorvejen)" (SWECO, 2020) has been selected as a case based on the criteria presented in section 3.3.5. Generally, the project concerns three proposals for extending a 9,4 km section of route 55 from Nykøbing Falster to Sydmotorvejen. The project's assessment of climate change impacts is positioned in the same chapter as the assessment of impacts on air quality, and only includes one life cycle phase: the operations phase, which is assessed quantitatively. To calculate the GHG emission impacts from the operation phase, the CO_2 emissions from the expected traffic on the road is calculated. The calculation is based on; the expected traffic volume, the composition of the traffic (heavy and light vehicles), expected driving distances in the defined area, and projected emission factors per. km for the substances emitted. Thus, traffic in the operation phase is the only activity assessed in regard to GHG emissions. The report does not consider potential GHG emissions from other activities nor the interrelations between the phases throughout the project's life cycle.

Figure 6.1 presents an illustration of LCT applied to the case, including an overview of life cycle phases and activities which may be relevant for this type of project. The red box represents the activities included in the report's assessment of GHG emissions. The added phases and activities are inspired from earlier LCA-studies of roads, and illustrations from The Danish Road directorate [Håkan Stripple, 2001], [The Danish Road Directorate, 2022].

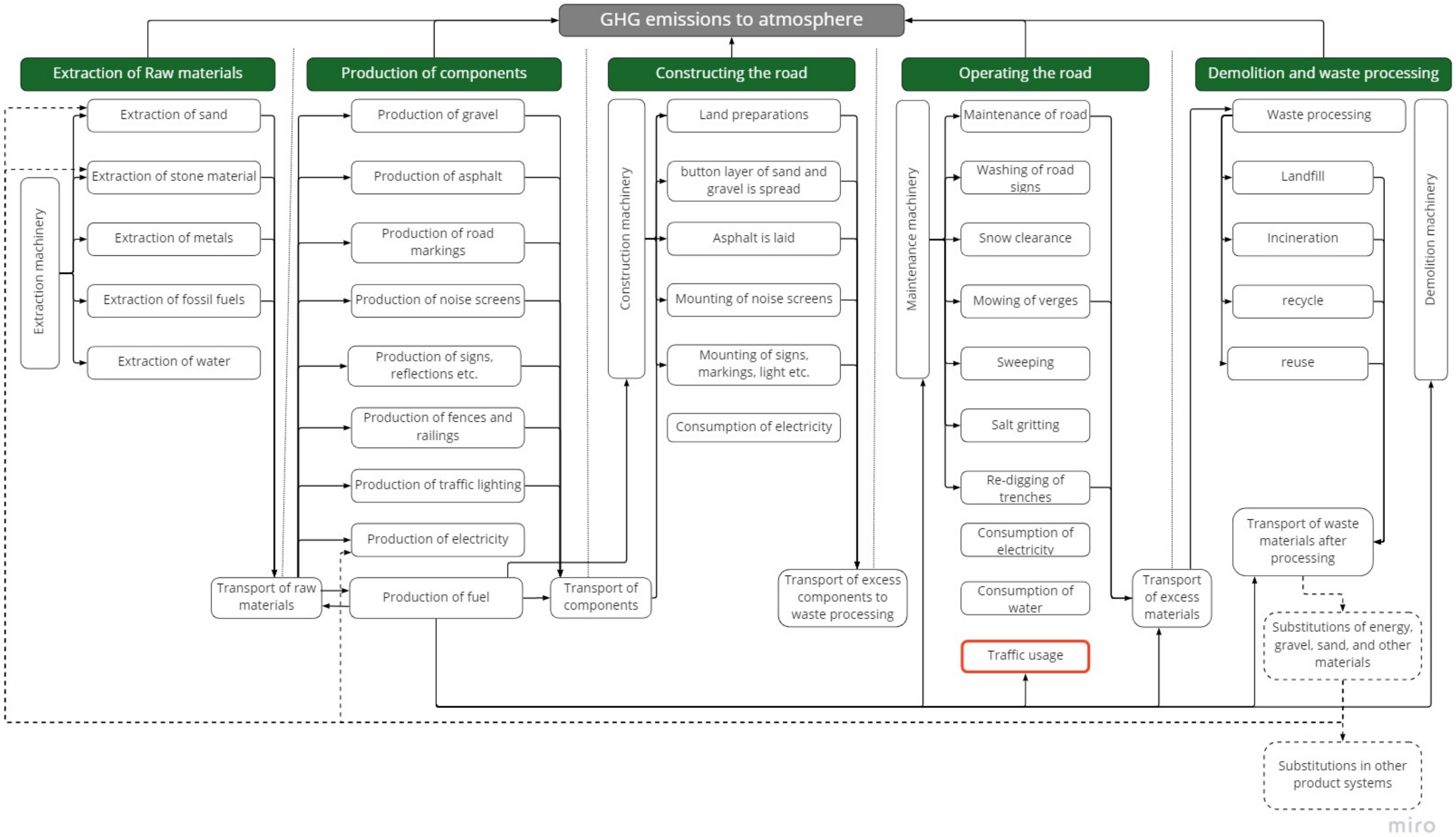


Figure 6.1. The potential life cycle phases and associated activities for a road project. Green boxes = life cycle phases. Red boxes = activities included by the case "Upgrading of 55 (Nykøbing F - Sydmotorvejen)". Dotted boxes = substitution scenarios.

The first life cycle phase "extraction of raw materials" covers activities that are needed in order to provide the necessary raw materials for constructing the road. An example of GHG emissions induced by this phase could be the use of extraction machinery. The raw materials are afterwards transported to the next life cycle phase "production of components". This phase covers activities needed to produce specific components e.g. noise screens and asphalt. GHG emissions from this life cycle phase could originate from e.g. fossil fuels consumed by various machinery needed in the production. Afterwards, the components are transported to the specific location of the road construction, and here the life cycle transitions to the next phase "constructing the road". This life cycle phase covers construction activities such as land preparations and assembly of components. After construction, the road is ready for use, thereby initiating the phase "operating the road". This phase includes all necessary activities for keeping the road operational i.e. maintenance, reparations, etc. Another important activity from this phase is the traffic on road throughout its life time. GHG emissions induced by these vehicles are also included as part of the emissions induced by the road. Finally, after many years in operation the road enters the last life cycle phase "demolition and waste processing". In this phase, activities that induce GHG emissions include demolition machinery, transport of materials, and machinery for waste processing. Some waste fractions, e.g. gravel or sand, have the potential to be recycled or reused in another product system. Doing so will substitute the production of new gravel and sand, which has positive effects on the GHG emission impacts. These potential substitutions are represented in the figure by the dotted arrows.

The fact that only one activity was included, indicates that the assessment of GHG emissions was conducted based on a narrow perception. It is unclear, whether LCT has been applied earlier in the EA process (e.g. in regard to scoping) for this case. However, the report does not include any justification as to why other phases or activities are not incorporated in relation to the assessment of GHG emissions.

LCA screening

The following will demonstrate how a simple LCA screening can be conducted for the case, with the purpose of performing a hotspot analysis, i.e. highlight which life cycle phases and associated activities should be included in the assessment of GHG emissions. The LCA screening is intended to exemplify how EA-practitioners can apply LCA in an EA context.

Therefore, the purpose of the analysis is to demonstrate a simple and uncomplicated approach to LCA modelling. In practice, this meant that activities were only included if data was available. The under laying methods for the LCA, including justification for functional unit, determination of system boundary, applied datasets and considerations about data assumptions can be found in section 6.1.1.

Data inventory and assumptions

In the attached annex, in sheets labelled "LCA - Wastewater treatment plant" and "LCA - Road project", the inventory tables both systems include specification of unit conversion factors, and links to the source material from where they derive.

Table 6.1 presents an overview of the included activities and applied data for the LCA of the road project: "Upgrading of E55 (Nykøbing Falster - Sydmotorvejen)". All data inputs are scaled according to an assumed life time of 22 years (based on the classification $T2_{heavy}$ [The Danish Road Directorate, 2018]), and normalised according to the functional unit.

Phase	Activity	Amount (entire life cycle)	Unit	Per FU	Unit	Background data
Production of components	Production of gravel	131.000	m^3	23.691.489	kg	Gravel, crushed GLO| market for | Conseq, U
	Production of asphalt	245.000	m^2	2.606.383	kg	Mastic asphalt GLO| market for | Conseq, U
	Transport of components			1.314.894	tkm	Transport, freight, lorry >32 metric ton, EURO6 RER| transport, freight, lorry >32 metric ton, EURO6 | Conseq, U
Construction	Fuel consumption			13.273.958	MJ	Diesel, burned in building machine GLO| market for | Conseq, U
	Energy consumption			1.363.410	kWh	Electricity, medium voltage DK | market for | Conseq, U
Operation	Maintenance - fuel consumption	75.275	l/km	290.650	MJ	Diesel, burned in building machine GLO | market for | Conseq, U
	Traffic usage			23.171	ton CO_2	
Demolition and waste processing	Waste treatment of gravel			23.691.489	kg	Waste concrete gravel RoW| treatment of waste concrete gravel, recycling | Conseq, U
	Waste treatment of asphalt			1.738	m^3	Excavation, skid-steer loader GLO| market for | Conseq, U
	Gravel substitution	-131.000	m^3	-23.691.489	kg	Gravel, crushed GLO| market for | Conseq, U
	Asphalt substitution	-245.000	m^2	-2.606.383	kg	Mastic asphalt GLO| market for| Conseq, U

Table 6.1. Inventory table for the case: "Upgrading of 55 (Nykøbing F - Sydmotorvejen)"

The activities included in this model, derive from a list of materials and amounts, specified in the EIA report. The list includes the required amounts of gravel and asphalt, which are therefore modelled as the only material inputs. This is also based on the assumption that the required amount of other materials is very limited in comparison. The required transport of materials to the construction site is also modelled. Due to a lack of data, it is assumed that the materials are transported over an average distance of 50 km, in trucks that can carry more than 32 tons.

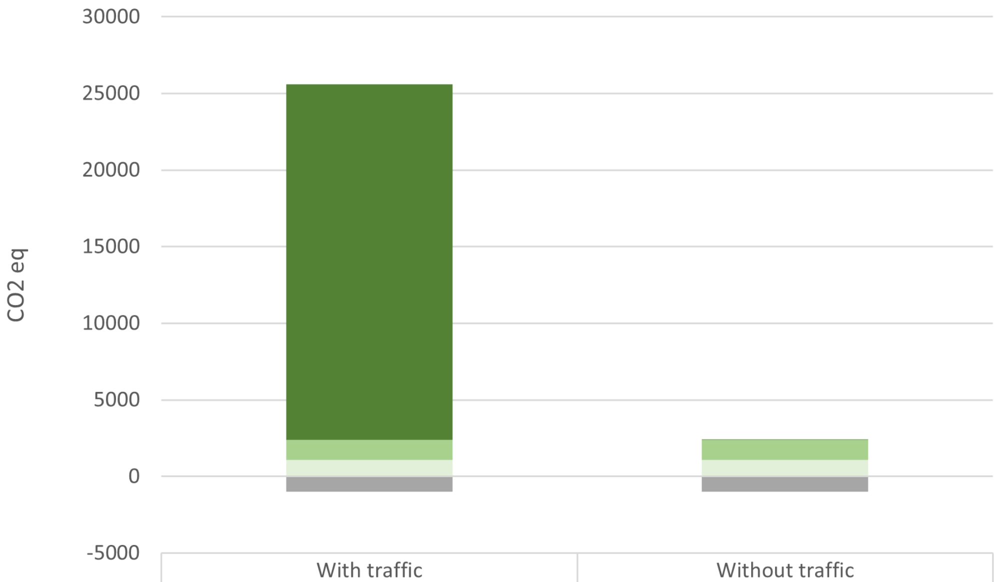
The EIA report does not provide any data regarding the construction phase. Therefore, the modelling of this phase is based on an aggregated data set for road construction (Road RoW| road construction | Conseq, U). The dataset specifies that road construction consumed 43 MJ of diesel pr. 85,19 kg of applied asphalt and gravel. Furthermore, it specifies that 15,9 MJ of electricity is consumed per 85,19 kg of applied asphalt and gravel.

Regarding the operations phase, the report presents an estimation of the annual CO_2 emissions from road traffic. This estimation accepted, and normalised according to the functional unit. The report does not provide any data regarding road maintenance, and the activity is therefore modelled based on a previous LCA study. The study specifies that road maintenance has a fuel consumption of 18200 l/km over a 50 year period [Mroueh et al., 2000], which is scaled and applied in the model.

No data regarding the demolition and waste processing phase could be found in the EIA report. Therefore, the modelling is entirely based on assumptions regarding how the materials are treated. It is assumed that the applied amounts of both gravel and asphalt can be reused in their entirety. Therefore, the end-of-life for these materials is modelled as both waste treatment and one-to-one substitution of virgin materials.

Results

Figure 6.2 presents the characterised results of 1 km of the road "Upgrading of 55 (Nykøbing F - Sydmotorvejen)". The negative values indicate avoided GHG emissions due to substitutions, whereas the positive values indicate contributions of GHG emissions. The results are given in two different scenarios; one including the emissions associated with traffic usage, and one excluding this activity. Traffic usage is modeled based on the results from the EIA report "Upgrading of 55 (Nykøbing F - Sydmotorvejen)" (SWECO, 2020).



	With traffic	Without traffic
Demolition and waste processing	-1000,623	-1000,623
Operating the road	23198,323	27,28323
Constructing the road	1296,382	1296,382
Production of components	1098,734	1098,734

Figure 6.2. Hotspot analysis of individual life cycle phases with and without the activity traffic usage. The figure include amounts for GHG emissions given in CO_2 equivalents for each life cycle phase.

As illustrated by the figure, GHG emissions are significantly larger in the scenario including traffic usage compared to the scenario without it. Therefore, it is evident that traffic usage account for a very large part of the total GHG emissions (90,1%) compared to other activities. As specified, traffic usage is the only activity included in the EIA report's assessment of GHG emissions. This priority correlated with the results presented in the figure, as traffic is by far the most notable activity. However, the approach to estimating the impacts from traffic usage can be criticised. In the EIA report (and in this LCA screening), the estimated traffic usage includes all transport on road throughout the entire life cycle (22 years). However, much of this traffic would also exist without the upgrade of the road, i.e. on existing roads. Therefore, it can be argued that a large proportion of the emissions from traffic are not depend on the upgrade of the road. However, it is noteworthy that some extra traffic would be generated by the road which should be included in the assessment. In other words, the emissions from traffic usage should only include the extra traffic generated by the road and not exciting traffic. Based on this notion, it is assumed that traffic usage will account for a significantly smaller amount of the total GHG emissions than presented in the EIA report. Therefore, another scenario where traffic usage is not included in the LCA screening has been conducted. Figure 6.3 illustrate a hotspot analysis of the scenario without traffic, represented in a flowchart.

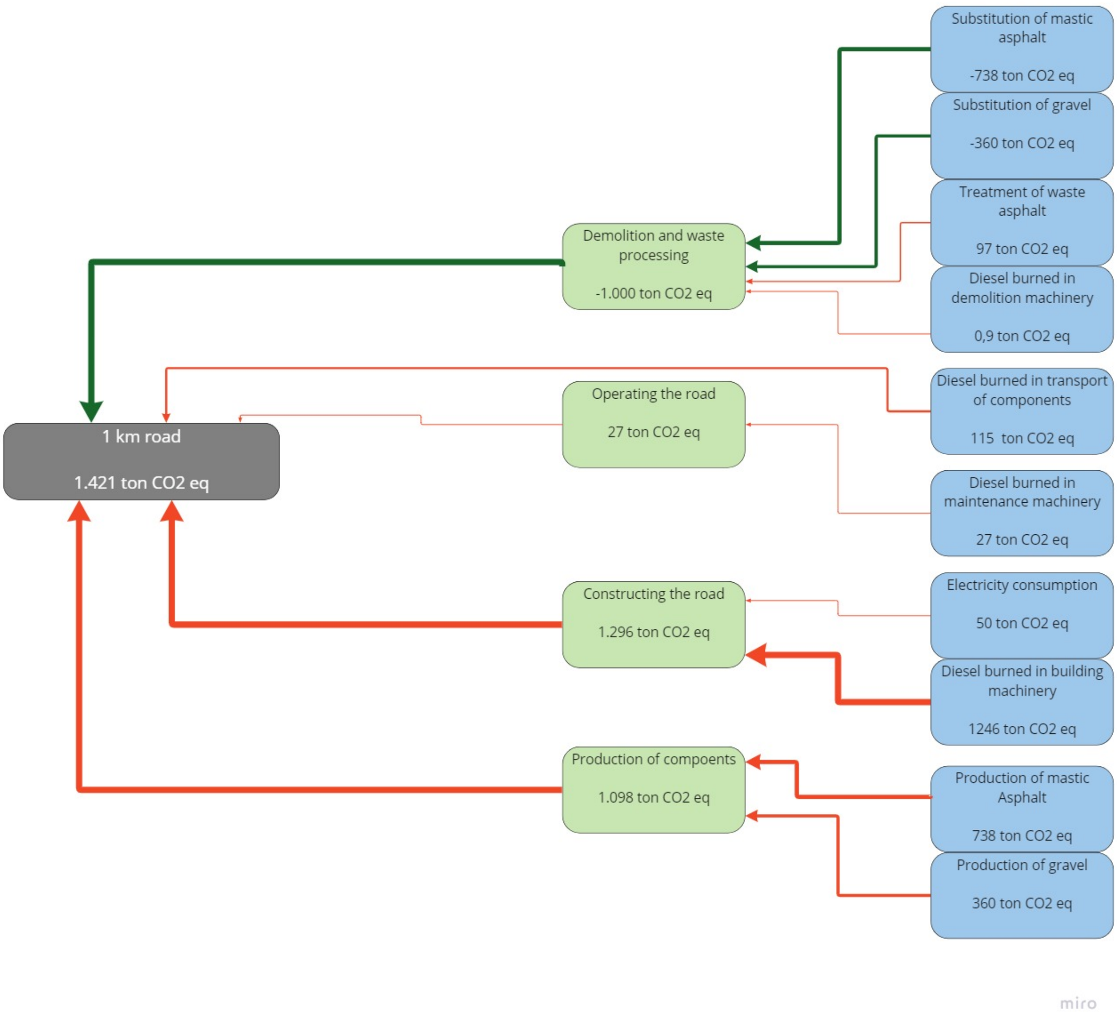


Figure 6.3. Flowchart of the hotspot analysis for the project "Upgrading of 55 (Nykøbing F - Sydmotorvejen)". The figure include amounts for GHG emissions given in CO_2 equivalents for the entire life cycle (grey box), individual life cycle phases (green boxes) and individual activities (blue boxes).

As illustrated in the figure, it varies which life cycle phases and activities constitute a large proportion of the total GHG emissions. It is mostly the life cycle phases: constructing the road (51,1%) and production of components (43,3%) which constitute a substantial amount of the negative GHG impact. More specifically, it is the activities; diesel burned in building machinery; production of mastic asphalt, and production of gravel that emits the largest amounts of GHG emissions. It is noteworthy that a substantial amount of GHG emissions are being avoided in the demolition and waste processing phase. This is due to the recycling of asphalt which substitute the production of new mastic asphalt, and the reuse of gravel which substitute the production of new gravel.

Overall, figure 6.3 illustrates a scenario where the GHG emissions are more distributed among the different life cycle phases and activities compared to the scenario with traffic usage. In this case the aforementioned life cycle phases and associated activities would be essential to include since they constitute a substantial amount of the total GHG emissions. Therefore, it can be argued that it would be insufficient only to include the traffic usage for this specific project.

6.1.3 Case 2: Wastewater treatment plant expansion

The second case, which has been selected for analysis, is an EIA report for "Expansion of Mariagerfjord wastewater treatment plant" (Orbicon/WSP, 2020a). The project concerns an expansion of the current treatment capacity from approx. 5.600.000 m^3/year to approx. 11.000.000 m^3/year. This entails the construction of a new tank system, machine building, sludge dehydration building, gas engine building, and silo/filter building. The capacity expansion would enable the plant to accommodate rising demand from industries and housing in the surrounding area (Orbicon/WSP, 2020a). Similarly to case 1, the assessment of GHG emissions is described in relation to impacts on air quality, and only includes two activities; emissions from transport by truck, and emissions related to the plant's anaerobic digestion facility (biogas production). The activities are both related to the operations phase, as assessment of impacts from the transport by truck, are based on an estimation of the induced effects on sewage sludge haul distances. It is estimated that the expansion of the plant will shorten transport distances overall, due to the increased capacity. The expansion is also claimed to induce substitution of natural gas-based energy production, due to the new plants ability to supply itself with enough biogas to cover energy demands (both heat and electricity). Thus, the assessment of GHG emission impacts exclusively includes positive effects of the project. Whether or not these impacts are the only relevant aspects related to the GHG emissions of the project is however questionable. Therefore, LCT has been applied as a means of identifying other relevant activities and phases. An overview of the findings is presented by figure 6.4.

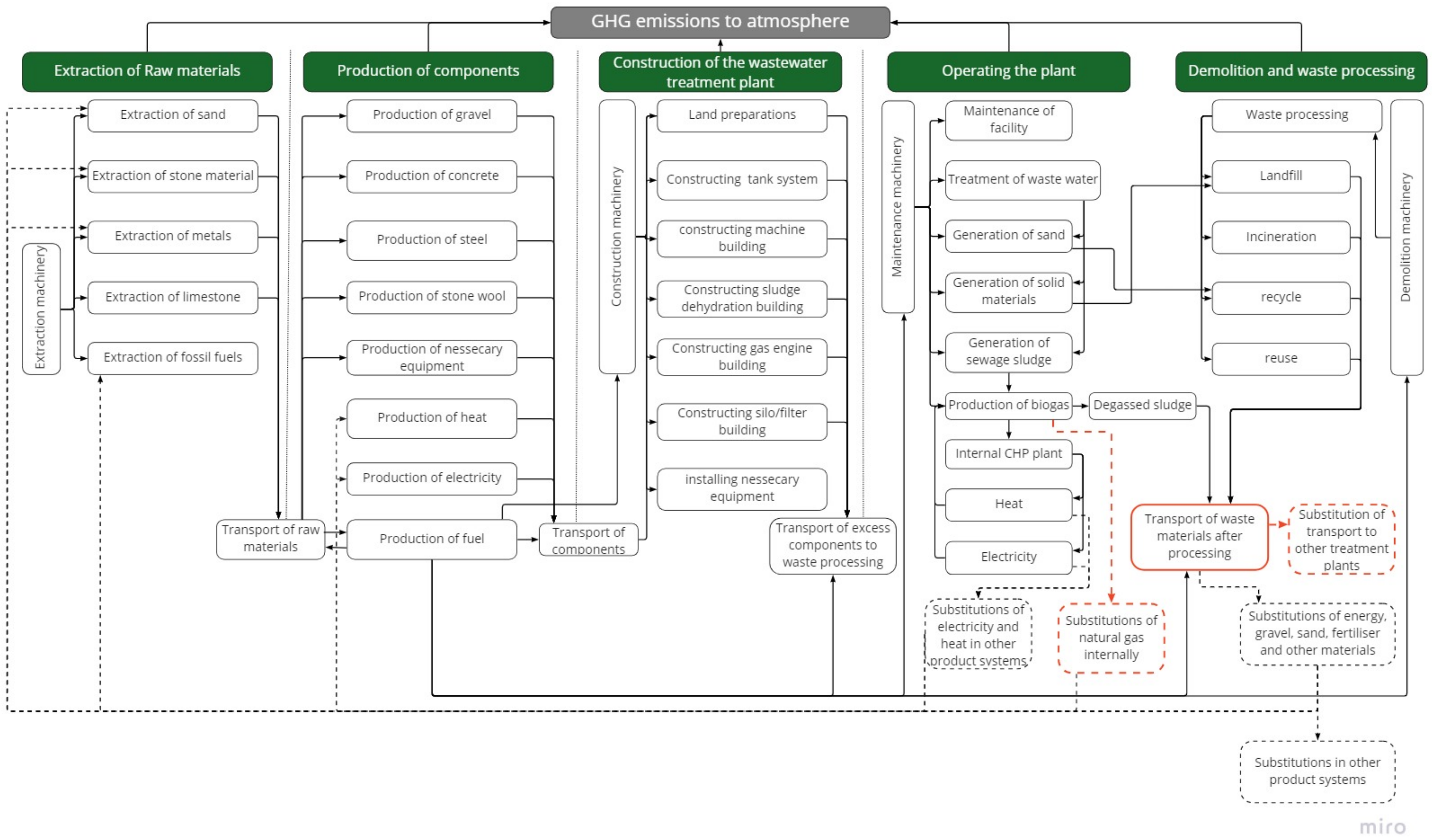


Figure 6.4. The potential life cycle phases and associated activities for a wastewater treatment plant. Green boxes = life cycle phases. Red boxes = activities included by the case "Expansion of Mariagerfjord wastewater treatment plant". Dotted boxes = substitution scenarios.

Similarly to "case 1: Road project" this clearly illustrates that the assessment is based on a limited part of the life cycle (indicated by the red boxes).

LCA screening

In order to demonstrate potentially relevant life cycle phases and related activities, a hotspot analysis is conducted.

Data inventory and assumptions

Table 6.2 presents the activities and data applied in the LCA model of the wastewater plant project: "Expansion of Mariagerfjord wastewater treatment plant". Based on an applied data set from ecoinvent (Wastewater treatment facility, capacity 5E9l/year CH| construction | Conseq, U) the assumed life time of the plant is 30 years.

Phase	Activity	Amount (entire life cycle)	Unit	Per FU	Unit	Background data
Production of components	Construction of the plant incl. Materials and transport	1,08	p	0,036	p	Wastewater treatment facility, capacity 5E9l/year CH| construction | Conseq, U
Constructing the facility						
Operations	Biogas production (substitution)	-64050	ton CO_2 eq	-2.135	ton CO_2 eq	
	Transport truck (substitution)	-904	ton CO2 eq	-30	ton CO_2 eq	
	Additional heat consumption (Natural gas)	180.000	MJ	23.7600	MJ	Heat, central or small-scale, natural gas Europe without Switzerland| heat and power co-generation, natural gas, 160kW electrical, lambda=1 | Conseq, U
Demolition and waste treatment	Waste treatment of sewage sludge	124.560	ton	4.152	ton	Raw sewage sludge (waste treatment) CH| treatment of, municipal incineration | Conseq, U
	Sewage sludge after anerobe digestion (substitution)	-134.940	ton	-605	ton	Nitrogen fertiliser, as N RER| calcium ammoniumnitrate production | Conseq, U
	Sand	-3.180	ton	-106	ton	
	Solid materials (ristegods)	1.500	ton	50	ton	Waste plastic, mixture GLO| treatment of waste plastic, mixture, unsanitary landfill, dry infiltration class (100mm) | Conseq, U
		1.500	ton	50	ton	Waste polystyrene GLO| treatment of waste polystyrene, unsanitary landfill, dry infiltration class (100mm) | Conseq, U
		1.500	ton	50	ton	Waste polyurethane GLO| treatment of waste polyurethane, unsanitary landfill, dry infiltration class (100mm) | Conseq, U
	Waste treatment of steel			111	ton	Waste reinforcement steel GLO| market for | Conseq, U
	Recycling of steel (substitution of reinforcing steel)			-46	ton	Reinforcing steel GLO| market for | Conseq, U
	Waste treatment of concrete			3.374	ton	Waste concrete, not reinforced Europe without Switzerland| market for waste concrete, not reinforced | Conseq, U
	Recycling of concrete (substitution of gravel)			-709	ton	Gravel, crushed CH| production | Conseq, U
	Waste treatment of rock wool			4	ton	Rock wool GLO| market for | Conseq, U
	Recycling of rock wool (substitution of rock wool)			4	ton	Waste mineral wool CH| market for waste mineral wool | Conseq, U

Table 6.2. Inventory table for the case: "Wastewater treatment plant Mariagerfjord"

As opposed to the road construction case, the EIA report for the wastewater treatment plant does not specify any materials to be applied in the construction of the plant. Therefore, a generalised data set, including both materials and construction activities is applied. The data set describes an average wastewater treatment plant in Switzerland, and was chosen because the alternative data set (RoW) includes inputs from various countries (e.g. energy mix). It is assumed that an average wastewater plant in Switzerland is more comparable to a Danish plant, than an average plant in the rest of the world. The plant in the data set has a capacity of 5.000.000.000 l/year, while the expansion of Mariagerfjord wastewater treatment plant will increase the capacity by 5.400.000.000 l/year. Therefore, it is assumed that scaling the data set by 108% will be representative of the plant expansion.

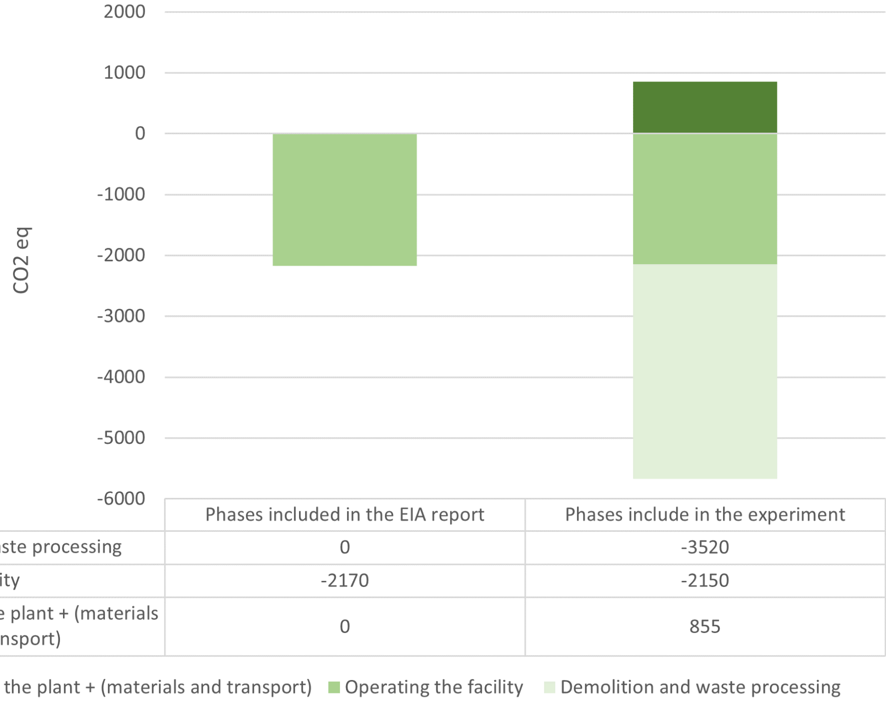
In relation to the operations phase, the EIA report presents an estimation of CO_2 displacement effects of implementing the project. The report states that the biogas production (and on-site gas powered engine), is adequate in making the plant self sufficient of both heating and electricity. Therefore, it is argued that this activity substitutes natural gas based heat and power production, leading to CO_2-emission savings overall. While acceptance of this claim depends on the definition of carbon neutrality, the choice is made to model the substitution according to the conclusions of the EIA report. The choice is somewhat based on the notion that biogas is a co-product[2] of wastewater treatment, as sludge is degassed before further use [Rudnik, 2013]. This means that the energy and heat consumption of the plant is modelled as a positive CO_2-emission impact, due to the substitution of a fossil based energy source. The report does, however, also specify that a reserve of natural gas is necessary for emergency situations, where the biogas production is too low, which is therefore also modelled. Lastly, the EIA report states that expanding the plant will lead to reduced CO_2-emissions due to shorter haul of waste materials from operations. This claim is accepted, and thus the transport during the operations phase is also modelled as having a positive impact.

The modelling of the demolition and waste treatment phase is based on several statements in the EIA report. Firstly, the report states that sewage sludge is applied as fertiliser after the anaerobic digestion process. Based on this statement, the activity is modelled as a substitution of chemical fertiliser. For the modelling of this substitution, it is assumed that 52% of the sludge is utilised as fertiliser (i.e. the proportion which was utilised in 2009 [The Danish Environmental Protection Agency, 2013]), while the remaining 48% is assumed waste treated by means of incineration. In a report by The Danish Environmental Protection Agency [2001], it is estimated that the nitrogen contents of sewage sludge is 4,3%. In the modelling of the substitution, the applied background data describes a fertilisers with a nitrogen contents of 32%. In order to account for the sludge's smaller contents of nitrogen, the substitution is scaled by a factor of 7,44:1. Secondly, it is assumed that the solid materials, which are filtered from the wastewater, are comprised of mixed plastics, polystyrene, polyurethane (each accounting for 33,33%). According to the EIA report, these materials are waste handled by the means of landfill, which is therefore the modelled activity. Finally, it is assumed that the primary building materials (as included in the background data set) can be recycled/reused to some extent, and therefore the end-of-life phase is modelled as both waste treatment and substitution. For steel and concrete, the background data sets respectively state that 41% and 21% of the materials can be reused. These amounts are modelled as substitution of virgin materials.

Results
Figure 6.5 presents the characterised results for the wastewater treatment plant. The results are presented with two different systems perspectives, one for the phases included

[2] International Organization for Standardization [2006a] defines a co-product as *"any of two or more products coming from the same unit process or product system."*

in the EIA report, and another with the phases included in the LCA screening.



	Phases included in the EIA report	Phases include in the experiment
Demolition and waste processing	0	-3520
Operating the facility	-2170	-2150
Construction of the plant + (materials and transport)	0	855

Figure 6.5. Hotspot analysis of individual life cycle phases according to the systems perspective for the actual EIA report, and the systems perspective for the experiment.

As illustrated by the figure, it is evident that the system boundary included in the LCA screening creates a more nuanced picture of the project's overall GHG impact, as compered to the actual EIA report. Especially, the phase demolition and waste processing have a noteworthy impact, as it accounts for the largest GHG emission substitution. In order to present a true estimate of the projects effect on GHG emission impacts, it is therefore essential to include this phase. Based on this, it can be argued that the scoping undertaken in this EIA report is insufficient, since the most substantial life cycle phase is neglected. This clearly illustrates how a simple LCA screening can be beneficial for highlighting which life cycle phases are important to include in the EIA report.

In order to illustrate a more detailed picture of the LCA screening conducted in this experiment, figure 6.6 presents the characterised results, where concrete activities are also included.

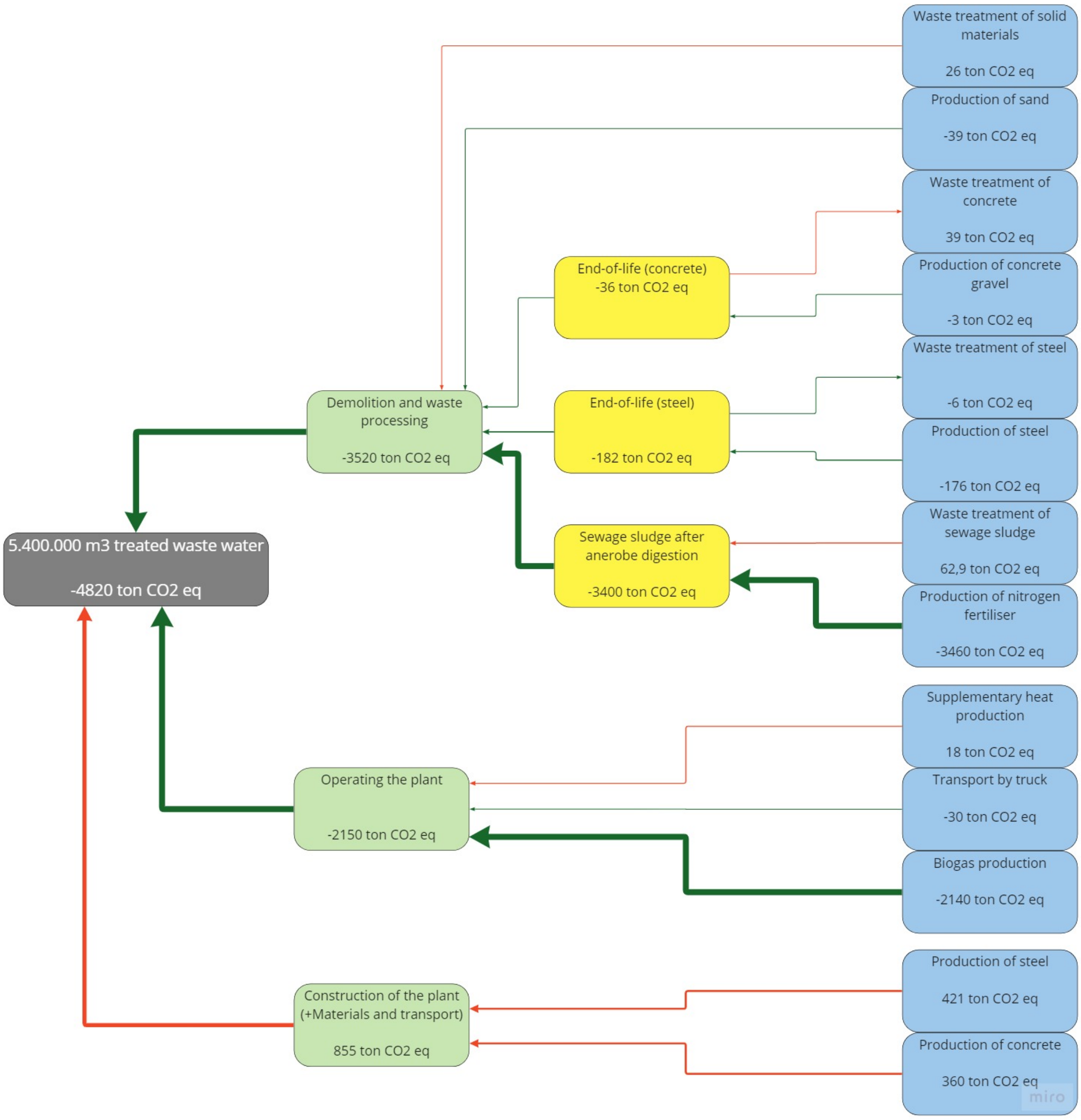


Figure 6.6. Flow chart of inputs and activities associated with the wastewater treatment plant. The figure presents GHG emissions in tons of CO_2 equivalents.

Overall, the results indicate that several relevant aspects have been neglected in the assessment of GHG emission impacts. Firstly, the activities related to the operations phase lead to displacement of CO_2-emissions. This is due to the effects of biogas substituting the burning of natural gas in the plant's heat and power supply. Thus, these results are heavily dependent on the assumption that biogas is carbon neutral. It could be argued that these results justify the report's inclusion of the operations phase in the assessment of GHG emissions, as biogas production is one of the most significant aspects related to the plant's GHG emissions. However, as the flowchart illustrates, it is certainly not the only relevant phase/activity. The transport by truck, which is also included in the report's assessment of GHG emissions, also has an overall reducing effect on GHG emissions of the project. The choice of only including these two activities could indicate a desire to present the project in a positive light. Furthermore, the transport has a relatively small GHG emission impact. This begs the question of why this was included rather than other, more relevant phases/activities. Overall this emphasises the importance of LCT application in EA processes.

The results illustrate that the construction phase accounts for an impact of 855 ton CO_2 eq, primarily resulting from production of steel and concrete. The emissions correspond to approx. 18 % of the project's total emissions and could therefore be considered to be a rather large impact. This exemplifies that failing to include life cycle perspectives can lead to neglect of potentially significant phases/activities. While the GHG emission impacts of the construction phase may be smaller than the displaced emission of other phases, it is still relevant, i.e. impacts hereof could possibly be mitigated. Thus, the choice to not include this phase, based on the argument that other phases have a greater impact, may lead to neglected potentials for climate impact mitigation.

The most significant phase in terms of GHG emission impacts, is demolition and waste processing. In this phase, utilisation of sewage sludge is by far the largest contributing factor, due to the assumption that sewage sludge can substitute chemical fertiliser. Even though the utilisation of sewage sludge holds great potential for reducing GHG emissions, the activity is not included in the report's assessment of GHG emissions. This further accentuates the importance of understanding the life cycle impacts of activities within the system. If LCT had been applied, this would have highlighted the benefits of utilising sewage sludge, thus emphasising that this activity should be prioritised.

6.1.4 Reflections and experiences

This section concerns reflections upon the application of LCT for EA purposes, based on the experiences gained throughout the experiment.

Modeling reflections
The following concerns reflections that arose on the basis of the LCA screening. More specifically these reflections concerns how choices of modelling have effected the LCA results, and how different approaches could have produced different outcomes.

As specified, the system boundaries of the conducted LCA screenings were determined based on available data from the EIA reports and external sources. Needless to say, this delimitation of included activities has affected the LCA results. However, it is worth considering how a different scope may have yielded different findings. As an example, methane release during anaerobic digestion of sewage sludge has not been included in the modelling of "Expansion of Mariagerfjord wastewater treatment plant". However, according to The Danish Energy Agency [2021], Danish treatment plants have an average methane loss of 11.7%. Due to the fact that the greenhouse effect of methane is around 23 times greater than CO_2 [Agriculture and Food, 2022], this loss would arguably contribute substantially to the GHG emission impacts of the plant. This example emphasises the importance of applying an LCT approach where the activities of the PPP are considered from a systems perspective. It also emphasis that individual activities can account for a substantial amount of the total GHG emissions.

Besides from GHG emissions, the LCA screenings conducted in this thesis could also be relevant for calculating many other environmental impacts. By applying a multi criteria method (e.g Stepwise[3]) the results could have contributed to a wider range of impact categories such as human health, resource depletion, etc. As an example, SimaPro provides an opportunity calculate impacts for the category "respiratory inorganics", which can be applied in assessing impacts on human health. This demonstrates that a higher incorporation of life cycle phases would not only be beneficial for the assessment of GHG emissions but also for other environmental impact categories as well.

Perspectives on EA practice

This section concerns reflections upon how EA practitioners would find LCT applicable for EA purposes. These considerations are based on the experiences gained throughout the experiment.

All authors of this thesis have some experience in LCT and LCA modelling, having completed courses and applied the tool in previous semester projects. This would not necessarily be the case for EA practitioners, and therefore it is uncertain whether the application of LCT would entail a learning process, or if the tool can be used directly. However, the required analysis for each environmental parameter are generally prepared by professionals with expert knowledge within specific areas. The task of the EA practitioner is to conduct the assessment based on the environmental analyses provided by the experts. This approach is also expected to be the case for the assessment of GHG emissions, and therefore, it is assumed that assessments equivalent to those conducted in this thesis would be conducted by individuals with LCA experience. Therefore, the lack of LCA know how amung EA practitioners may not be an issue, as the task of modelling is given til individuals with LCA competences.

The experiment has demonstrated that applying LCT exclusively as a qualitative tool can at the very least ensure that all life cycle phases and associated activities are considered. Even though figures 6.1 and 6.4 do not highlight which activities are contributing most significantly to GHG emissions, they are applicable for creating an overview of the entire life cycle. Furthermore, the figures illustrate the relations between life cycle phases and activities (illustrated by the arrows), which may improve the understanding of how activities are interconnected. Thus, creating an LCT-based overview can prove beneficial in terms of expanding EA-practitioners' perceptions of the entire life cycle of a PPP, and the interrelations of activities. While this exercise will not necessarily lead to a greater inclusion of life cycle phases in EA reports, it will ensure that all phases are considered, which should be the bare minimum.

Applying LCT quantitatively through an LCA screening has proven beneficial for identifying the life cycle phases which are most important to include in the EA report. Furthermore, the experiment has revealed challenges of LCT application, which may or may not be present for EA practitioners. The experiences from the LCA screening are mainly related to modelling- and data considerations, rather than appertaining to more basic challenges, e.g. how to use LCA software, or how to construct an LCA model.

In order to benefit from LCT, it is necessary to comprehend the elements that a PPP system is comprised of. Gaining an understanding of the project systems turned out to be a challenge when conducting the LCA screenings. For this part, the authors relied on the

[3] [2.-0 LCA consultants, 2020]

EIA reports, which did not necessarily provide a solid basis for understanding the systems. As a result many of the assumptions, on which the modelling is based, are entirely based on statements from the EIA report. However, this challenge would not necessarily be the case for EA practitioners, as they have a direct link to sources (developer) which can provide information about the PPP system.

One of the main challenges in conducting the LCA screening was gathering data for the foreground system. Here, the authors had to rely on the EIA reports for specification of materials, activities, and amounts. For instance, the EIA report for the road project included a basic list of materials, which was applied in the model. This was, however, not the case for the wastewater treatment plant, and an aggregated background data set had to be applied to account for the construction/raw materials phase. In practice, it could be argued that EA practitioners would have access to more specific foreground data through their clients, and would perhaps not encounter the same challenges. However, it could be argued that the availability of data varies greatly between PPPs. In some situations, specific materials and amounts, supplier specifications etc. may not be clarified at the time the EA reports is conducted (e.g. screening or scoping). In order to conduct an LCA screening in these cases, a publicly accessible database with aggregated amounts for various PPP types is therefore needed.

6.2 Determination of significance

As the findings presented in section 4.2.2 demonstrate, Danish EA reports generally lack transparent-, consistent-, and sufficient approaches for significance determinations of GHG emission impacts. This is based on the notions that several different reference categories are applied in determining significance, and that the majority of these are regarded as insufficient.

It is evident from the previous sections that the use of LCT provides a more well-founded assessment, which is why LCT is proposed as an approach to ensure more adequate significance determinations. However, the references applied to compare the impacts are still considered crucial. A qualitative or quantitative analysis of hotspots, i.e. identifying where the most significant emissions that may occur throughout the life cycle, can be a helpful tool in identifying areas which need to be prioritized for action, and thereby activities which may be significant. Thus, a hotspot analysis can be used to compare a PPP's activities in order to get an idea of the magnitude of different impacts.

Moreover, the impacts of one PPP can be compared to the impacts of other similar PPPs in order to get an impression of the significance. Though, to attain an adequate and relevant comparison, it is essential to apply the same standard of reference. A FU is applicable in this regard, as it quantifies the function of the PPP and thereby provides a unit suitable for comparison. Besides from comparing similar PPPs, a FU can also be applied in order to compare alternative ways of providing the same function. Nevertheless, it is important to ensure that similar methodological choices have been applied. In this regard, International Organization for Standardization [2006a] emphasises that: *Comparing the results of different LCA or LCI studies is only possible if the assumptions and context of each study are equivalent.* Therefore, if a FU is used to compare a PPP to another similar PPP in order to get a grasp of the degree of significance, it is important to be aware of the comparability, e.g. whether the same system boundary has been applied.

IEMA [2022] introduces another approach to determining significance which involves LCT. It is proposed that the significance of a project's GHG emission should be based on its net impacts throughout its life time. In order to assess this, consideration of the PPP's life cycle and associated activities is necessary. However, the organisation also asserts that:

> *"The crux of significance therefore is not whether a project emits GHG emissions, nor even the magnitude of GHG emissions alone, but whether it contributes to reducing GHG emissions relative to a comparable baseline consistent with a trajectory towards net zero by 2050."* [IEMA, 2022,p. 24]

Hence, according to IEMA [2017], the significance determination should not only be based on the magnitude of the impacts but take into account the PPP's contribution to climate targets. Therefore, LCT cannot stand alone as a solution for improving the significance determination as reference for comparison is still needed.

Based on these acknowledgements, LCT and the use of associated concepts within the field are proposed as approaches to obtain more adequate determinations of significance. However, the approaches cannot stand alone obtaining sufficient significance determinations, as they only give an estimate of the GHG emissions' magnitude. As proposed by IEMA [2022], impacts could be compared to a net zero trajectory, in line with climate goals, to determine significance.

6.2.1 Suggestion: Threshold values

In order to determine significance, this thesis suggest that threshold values, consistent with the Danish climate goal of 70 % reduction of GHG emissions in 2030, should be developed for different types of PPPs (e.g. construction, waste handling, and infrastructure). Threshold values already exist for other EA topics, such as air quality [Ministry of Environment of Denmark, 2017] and noise pollution [The Danish Environmental Protection Agency, 2022c]. Recently, threshold values for CO_2 emissions have been proposed in a new strategy for sustainable construction The Danish Parliament [2021]. This strategy introduces a threshold value to the Danish building regulations (as per 2023), concerning the GHG emission impacts of new buildings larger than 1000 square meters [The Danish Parliament, 2021]:

- 12 kg CO_2 eq/m^2/year (required)
- 8 kg CO_2 eq/m^2/year (optional)

Hereby, an actual requirement for the maximum CO_2 emissions is proposed. The strategy entails that stricter threshold values are continuously phased in, based on the most recent knowledge. Furthermore, the strategy sets requirements for the application of LCA to provide an estimate of the building's GHG emissions over its entire life cycle [The Danish Parliament, 2021].

Based on the conclusions of section 6.1, it is argued that the implementation of threshold values for GHG emissions would still impose the need for LCT, in order to obtain quantitative estimations of a PPP's GHG emissions. If a PPP's GHG emissions do not uphold the threshold value, then the impact would be significant and would have to be mitigated. A development of acknowledged threshold values for GHG emissions consistent with Danish climate targets can provide a sufficient approach to determining significance. However, in order to do so, it is necessary to create standardised approaches for conducting GHG emission calculations. This notion is also emphasised by Weidema [2022]:

> *"I would like to see a standardized format [for conducting LCA, ed.] where you simply say, these things need to be included, and it needs to be conducted using this method in order to allow for comparison. In my opinion, this would make the whole thing faster and easier."* [Weidema, 2022]

Hereby, Weidema [2022] suggests that a standardised approach could include specifications for what needs to be included in terms of life cycle phases and activities, and specifications for which methods should be applied. Furthermore, it can be argued that ensuring consistency in applied functional units, and access to the same generalised datasets are required, and thus must be included in a standardised approach.

Even though this suggestion for significance determination can bring improvements to the current practise, a point of critique can also be given. In order to assess whether a ppp contribute to the achievements of climate goals by living up to fixed threshold values, it is necessary to perform some kind of quantitative assessment based on the characteristics of the PPP. In this regard LCA is very useful, however lack of sufficient knowledge from the PPP can make it difficult to produce useful results that are true to reality. Due to the fact that SEA operate at a strategic level, where limited knowledge about specific characteristics of the plan is available, it can be difficult to perform such calculations. Therefore, the suggestion regarding significance determination is more applicable in cases where a sufficient knowledge is available.

6.3 Sub-conclusion

Based on the findings in this chapter it can be concluded that LCT has potential to complement the EA practice, and the issues identified in chapter 4. Through an experiment, it has been demonstrated how LCT and an LCA screening can be used to improve impact assessment of GHG emissions in EA. Firstly, LCT applied qualitatively (e.g. by preparing a flowchart) is applicable for providing an overview of the full life cycle, thereby contributing to a more holistic understanding of the entire project life cycle, and how the different activities are interconnected. Secondly, LCT conducted quantitatively through an LCA screening has proven beneficial in terms of identifying which life cycle phases and associated activities are essential to include in order to present accurate results. This has the potential to emphasise the need for a greater inclusion of more life cycle phases in GHG emissions assessments conducted in EA reports. Additionally, it has been argued that LCT is adequate for providing an accurate estimate of a PPP's GHG emissions, which can be an applicable foundation for more adequate determinations of significance. However, it should be noted that LCT cannot stand alone as a means to obtaining sufficient significance determinations, as the approach only provides an estimate of the GHG emissions' magnitude. In order obtain a sufficient reference for significance determination it has been suggested that threshold values, consistent with Danish climate goals should be developed for each different PPP type.

Based on these conclusions, three points can be provided as recommendations to current practice.

1) As a minimum, **LCT should be applied** in order to ensure that all life cycle phases and associated activities are considered.

2) **LCA screening should be conducted** in order to identify which life cycle phases and associated activities are contributing most significantly to GHG emissions. This practice is highly beneficial in terms of selecting which activities are most essential to include in the EA report.

3) There is a need for more standardised approaches to the determination of significance. Therefore, legally enforced **threshold values for GHG emissions should be implemented** in order to provide a consistent approach.

7 Discussion: Institutional context

Previous chapters have established that the current practice of GHG emission assessment in EA, is insufficient regarding the inclusion of life cycle phases and significance determination. However, the question of why the practice is as such, has yet to be answered. Therefore, the purpose of this chapter is to explore underlying aspects of the practice, with the aim of discussing where the practice of GHG emission assessment is heading. These aspects will be investigated through institutional theory, and build upon results from the previous chapters and new perspectives.

The institutional setting can help explain why practice is shaped as it is, as explained in section 3.4. Therefore, the following sections look into the three pillars of institutional theory: the regulatory, normative, and cultural-cognitive, and how they each is shaping the current practice by either facilitating or constraining it.

7.1 The regulative pillar

The regulative pillar concerns formal laws and rules [Scott, 2008]. In an EA context, examples of aspects within this category include; EA legislation, EA guidance documents, the competent authority, and verdicts/settlements of the Board of Appeal.

EA legislation sets the framework for EA practice, and its purpose is to regulate EA assessments and thereby ensure a high level of environmental protection. Though, it may be questioned whether the legislation actually provides a proper framework for obtaining sufficient GHG emission assessments. The regulatory institutions do not set specific requirements for an application of LCT, however IAIA emphasises in the "International Best Practice Principles - Climate Change in Impact Assessment" that:

> *"The IA should estimate the composition, magnitude, and intensity of GHG emissions for each relevant element and phase of the proposal. This should be estimated by using a life-cycle approach* and should include any effects of the proposal on carbon sinks." [IAIA, 2018,p. 2]

Several other of the EA guidance documents briefly touch upon the notion that LCT or LCA can be applied for obtaining a detailed GHG emission assessments ([IEMA, 2022; The European Union, 2017a, 2013b,a]). However, Björklund [2022] and Ramshev [2022] agree that if legal requirements are not established then LCT or LCA properly will not be implemented either:

> *"I mean as long as it's [LCA, ed.] not required, it's not going to happen. Once it is required then everyone will scramble to do it."* [Björklund, 2022]

> *"(...) and if it is not a requirement from the authorities [to use LCA, ed.], then very few of my clients think it's a good idea that we spend a lot of time on, with an hourly wage."*

The quotes show how the regulatory pillar is influencing the EA practice, indicating that actions will most likely not take place, if they are not required. This aligns with the findings in previous chapters showing that few life cycle phases are included in GHG emission assessments. Hereby, the regulatory pillar contributes to upholding the practice for not applying LCT.

The competent authority enforces the rules and laws and is therefore also part of the regulatory pillar. Though, it is important to distinguish between different types of authorities and their assignments. The Danish Ministry of Environment formulates and presents the legislation, while The Danish Environmental Protection Agency provides guidance on upholding the legislation. Furthermore, the competent authorities e.g municipalities put law into practice through approval/rejection of PPPS. Hence, different authorities' standpoints and actions contribute to shaping EA practice. Ramshev [2022] gives a few examples of how a competent authorities act due to their role:

> *"In our dialogue with the Danish Environmental Protection Agency, they have stated that: "We consider it adequate that you make a climate impact calculation for your industrial plant, but the comparison to other products (...) is not our requirement." In this regard, you could say that the environmental assessment tool concerns the assessment of a specific project - It is not an assessment of the project's product."* [Ramshev, 2022]
>
> *"So if it [the law, ed.] states '[assessment, ed.] of the specific project', I think the authority believes that this is what needs to be accounted for (...) So the authorities' statements are very much locked by the specific text [in the law, ed.]."* [Ramshev, 2022]

Thus, the competent authority is bound by the specifications in the law, and are therefore unable to demand that EA reports include life cycle perspectives. However, it could be argued that the law could be interpreted as requiring life cycle perspectives to some degree.

The EIA directive sets specific requirements for the description of the likely significant effects to *"cover the direct effects and any indirect, secondary, cumulative, transboundary, short-term, medium-term and long-term, permanent and temporary, positive and negative effects of the project."* (cf. Annex IV, point 5) [The European Union, 2014,p. 17]. It can hereby be discussed whether the impacts induced by product of a PPP is as an indirect impact[1], and thereby whether it should be included or not. In this regard, Ramshev [2022] emphasises:

[1]EU defines an indirect impact as: *"Effects/impacts that occur away from the immediate location or timing of the proposed action, e.g. quarrying of aggregates elsewhere in the country as a result of a new road proposal, or as a consequence of the operation of the project (see also secondary effects)."* [The European Union, 2013a,p. 7]

> *"Perhaps you need to be more explicit in assessing climatic factors in environmental assessments, and perhaps you need to look more beyond the specific project. But this is something that the authorities must demand. After all, it is the environmental planning authority that must assess it."* [Ramshev, 2022]

In the quote, Ramshev [2022] points out that the legislation can be a driver for change, and that planning authorities should seek to uphold it. Thus, if more specific requirements are set for the assessment of GHG emission impacts, then the practice would have to adapt.

Another example of how a formal institution addresses GHG emission assessments is illustrated by the "Guidance on assessment of consequences for climate, environment and nature" developed by The Danish Ministry of Climate, Energy, and Utilities [2020]. The ministry communicates:

> *"In principle, no effects on greenhouse gas emissions from product consumption should be taken account of, e.g. concrete for energy systems, roads etc."* [The Danish Ministry of Climate, Energy, and Utilities, 2020,p. 5-6]

This is not directly linked to EA, but shows that regulatory institutions do not encourage actors to apply life cycle perspectives, as they do not emphasise a need to take GHG emissions related to product consumption into account. The quote can be seen as an example of how a regulatory institution articulates the scope of GHG emission assessments and thereby how they create and convey meaning in this regard. Based on the above-mentioned, it could be argued that regulatory institutions are maintaining current GHG emission assessment practice, as opposed to advancing it. In contrast, EU's guidance on integrating climate change and biodiversity into EIA and SEA, and IEMA's guidance on assessing greenhouse gas emissions and evaluating their significance, provide considerable recommendations on how to address GHG emissions [The European Union, 2013a,b; IEMA, 2022]. However, based on the results in previous chapters, it does not seem that practitioners use them. While this can be criticised, it could also be argued that guidance documents lack specificity in regards to assessment approaches and methods.

The Danish Environment and Food Board of Appeal is another institution within the regulatory pillar which shapes EA practice. As an example, the Board of Appeal decided to revoke the environmental permit for a large Danish pipeline project (Baltic Pipe), granted by the Danish Environmental Protection Agency in 2021. The ruling was based on the strict protection regime for Annex IV species, resulting from the EU Habitats Directive, which has halted the project for an indefinite period of time. The competent authority was obligated to carry out the supplementary studies necessary to assess whether the Annex IV species would be affected [Danish Environment and Food Board of Appeal, 2021]. The example shows that a project is halted due to strict legal requirements for the environmental factor biodiversity. It could be argued that because the state of biodiversity is considered critical [Rockström et al., 2009], regulations impose a "zero tolerance" regime. However, similar restrictions do not apply for climate, indicated by the notion that assessments of GHG emission impacts rarely result in stopping PPPs. This is despite of the fact that GHG emissions are contributing to a climate situation that can be considered critical [IPCC, 2021]. Based on the same argumentation as for biodiversity, impacts that contribute to climate change should also be considered critical.

However, GHG emission restrictions are developing within other fields. For instance, a political agreement was reached in March 2021 on a national strategy for sustainable construction. The agreement entails introducing requirements for calculating the GHG emission impacts of buildings, which are set to be implemented in the Danish building regulations by 2023. Specifically, they concern the application of LCA calculations, and specify limits for the carbon footprint of new buildings The Danish Parliament [2021]. This reflects how climate is understood and regulated within other fields. In addition, the strategy is an example of how it is possible to set threshold values for GHG emissions, which could be a help to determine significance within EA processes.

Overall, the regulative institutions mostly maintain the current EA practice of assessing GHG emission impacts. However, guidance documents provide a framework for obtaining best practice. Moreover, the regulative institutions have potential to drive the practice forward by setting stricter requirements for the assessment of GHG emission impacts.

7.2 The normative pillar

The normative pillar concerns social obligations, habits, and what is perceived as appropriate behaviour [Scott, 2008]. In relation to EA practice, the normative pillar can be seen as expectations from the public, the norm for assessing GHG emissions, and guidance documents providing recommendations for best practice.

Guidance documents lay down the appropriate practice for assessing GHG emissions and describe how it can be accomplished. Though, it seems that there is only a norm for following the guidance documents (applying zero alternative as reference for comparison), if GHG emission impacts have a positive nature (as described in chapter 4). The explanation could lye in other normative elements, such as norms regarding the how to meet expectations of developers, or the cultural setting which may not leave a lot of extra time to go through guidance documents. The normative practice may also be influenced by the regulative pillar as a lack of demands from regulations can create a norm for just following the minimum requirements.

The following quote from an EIA report regarding upgrading of a road illustrates what is perceived to be the norm for GHG emission assessments:

> *"There are no established methods for assessing whether or not an amount of emissions is acceptable. All man-made activities and consumption result in CO_2 emissions. It is therefore a normal practice to convert an annual CO_2 emission to a number of persons' annual emissions from consumption."* (EIA: Upgrading of 55 (Nykøbing F - Sydmotorvejen), SWECO, 2020, p. 127)

Hereby, the 'normal practice' for assessing GHG emission impacts is perceived to be a conversion of the project's GHG emissions to the corresponding annual emissions from a number of people. This could also explain why "annual emissions comparison" is identified as the second most applied reference category for determining significance in EA reports (cf. section 4.2.2). In addition, the quote gives an indication of why this approach is so widespread - there is no threshold value for GHG emissions. However, it seems that practitioners accept this norm, and do not seek to challenge or improve it for instance by looking into guidance documents. IPCC has explicitly stated that human induced GHG emissions have lead to climate change impacts on a critical level [IPCC, 2021] and based on current political initiatives, it is anticipated that Denmark will only have reached a 57% reduction of GHG emissions by 2030, as opposed to the committed goal of 70% [Danish Energy Agency, 2022]. Despite of this, the findings of section 4.2.2 indicate that it is common practice among EA practitioners to assess most GHG emission impacts as insignificant.

This indicates a lack of consideration of the current climate situation in EA practice. There may be multiple explanations for this tendency, which are rooted in the three pillars. These include superficial legislation, and a lack of conditions from public authorities, lack of knowledge in terms of climate vulnerability, misunderstandings of climate change impacts, etc. In recent years, increased attention has been drawn to climate impacts resulting from PPPs. These are examples of headlines in Danish news:

"Severe climate critique of plans for port expansion in Aarhus, called 'business as usual' by professor" [DR, 2022]

"The largest port in Denmark wants to expand. But 1.000 container ships are missing from the climate impact calculations" [Information, 2022]

"The government's infrastructure plan is criticized for a lack of CO_2 reduction benefits" [Information, 2021]

"Debate: Lynetteholm has been sold as a climate friendly project, but may end up as a climate impact" [Byrummonitor, 2021]

The headlines illustrate that several PPPs have been criticised due to a lack of climate focus. It can be argued that the media and attitudes of the public have an influence on what is perceived as appropriate behaviour, and thereby contribute to shaping the normative EA practice. Thus, the increased attention on GHG emission impacts may be reflected in future EA practice of assessing GHG emission impacts.

The number of responses received in relation to the public hearing of the plans for expansion of the port of Aarhus is an example of how public opinion can influence future practice. Over 1200 responses were received, including responses directed at the GHG emission impacts resulting from the project [DR, 2022]. Generally, the project/plan is criticised for comparing with annual national emissions, and for neglecting the seemingly large contribution of GHG emissions [Information, 2022]. This example is not solitary, and other EA reports are criticised for poor GHG emission assessments. Other examples include; the infrastructureplan 2035 [Information, 2021], the third Limfjord crossing [TV-2, 2022], and Lynetteholm [Byrummonitor, 2021]. Based on these examples, it could be argued that poor GHG emission assessments are beginning to attract more attention, thus giving rise to a change in how current GHG emission impacts assessments are conducted. Hence, the normative elements put pressure on business as usual. However, a municipal researcher at the Danish School of Media and Journalism, questions whether the concerns of the public will actually make difference, arguing that politicians have already made their decision at this point [DR, 2022]. Thus, it is uncertain how much influence the normative elements can have.

It can be deduced that the EA practice of assessing GHG emissions is currently under development due to pressures from normative institutions. However, there still is a long way to go as the expectations of the public need to be adopted by the practitioners before practice can evolve.

7.3 The cultural-cognitive pillar

The cultural-cognitive pillar concerns shared systems of understanding and meaning resulting from common beliefs on how things ought to be. In an EA context, this encompasses the practitioners' framework of understanding and conceptions from EA research.

Based on the results from section 4.1, the EA practitioners' perception of the quality of the GHG emission assessments differ. Not all practitioners perceive the quality of assessments as poor. However, the results of chapter 4 have shown that most assessment are insufficient. Combined with the fact that most impacts are assessed to be insignificant, this could indicate that some practitioners do not perceive the current climate situation as critical. Furthermore, it could also indicate that some EA practitioners misunderstand the characteristics of climate impacts. As an example, one SEA report states:

> *"Direct GHG emissions and air pollution will occur during the operational phase due to transport of personnel and equipment plus the use of equipment during maintenance work. Together, these emissions are expected to have a insignificant impact, as they are spread over a large geography and with good conditions for rarefaction."* (SEA: Environmental assessment of Thor Offshore wind farm sub-report 1: Non-technical summary and overall assessment, 2021, p. 42)

Regardless of geography or intensity, GHG emission impacts are cumulative by nature, as they contribute to global climate change [IEMA, 2022]. Nevertheless, this quote argues that GHG emissions are insignificant because they are spread over a large geography and with good conditions for rarefaction. However, these conditions do not influence the significance of the impact, which thereby indicates a misunderstanding of how GHG emissions effect the climate. Another common misinterpretation is that GHG emission impacts are insignificant due to the range of the impact:

> *"During the construction of the solar energy plant, the traffic during the construction phase will locally result in minor increased emissions to the surroundings, which are insignificant."* (EIA: Environmental Impact Report - Solar energy plants at Bjerndrup, COWI, 2020, p. 81)

In the quote, it is argued that the impact is insignificant and that it only occurs locally. However, GHG emissions impacts are global by nature, thereby not only affecting local conditions. This indicates a lack of understanding of climate impacts. These two quotes are similar in the sense that climate is assessed along with impacts on air quality. Thus, it could be deduced that the assessment of impacts on air quality overshadow the assessment of GHG emissions, when the two environmental factors are merged into one. Hence, a culture exists for assessing these two environmental factors together, often resulting in misinterpretations and neglect of the climate impacts.

Research within the field of EA contributes to shaping and changing the cognitive understanding. For instance, this thesis sheds light on the current practice of assessing GHG emission impacts and the potential improvements regarding significance determination and life cycle phases. This contributes to creating a new shared understanding of how GHG emission assessments ought to be. Thereby, research can contribute to creating a push towards improving GHG emission assessments. Results from section 4.1 show that some practitioners already experience a pressure/demand for improving GHG emission assessments. This pressure/demand may be resulting from both the normative institutions i.e. the public's expectations for practice, and the cultural-cognitive institutions i.e. researchers' belief of how practice ought to be. However, Ramshev [2022] touches upon how an existing culture can act as a barrier for change:

> *"So there's always a barrier if people have not tried it before [LCA, ed.], it's something new, and how do you incorporate it? You could call it a cultural barrier of some kind."* [Ramshev, 2022]

Hereby, the cognitive and cultural elements may constrain the GHG emission assessments if they maintain a common preference for business as usual. Thus, cultural-cognitive institutions must also develop in order to improve the GHG emission assessments.

Generally, it is a common conception that assessment of GHG emissions are of somewhat poor quality, which could indicate that greater attention will be given to the topic. In addition, practitioners experience pressure/demand for improving practice, and researchers also push for change. These notions indicate that the practice is under development. However, cognitive misunderstandings regarding the characteristics of GHG impacts and a culture of assessing climate along with air seems to constrain this development.

7.4 Conclusion

It can be concluded that elements within the institutional pillars (regulative, normative, and cognitive-cultural) generally contribute to constraining the current EA practice of assessing GHG emissions. However, several elements have also been identified as pushing for change. Figure 7.1 presents an overview of the institutional elements related to each pillar which either are constraining the EA practice of assessing GHG emission impacts or driving it forward.

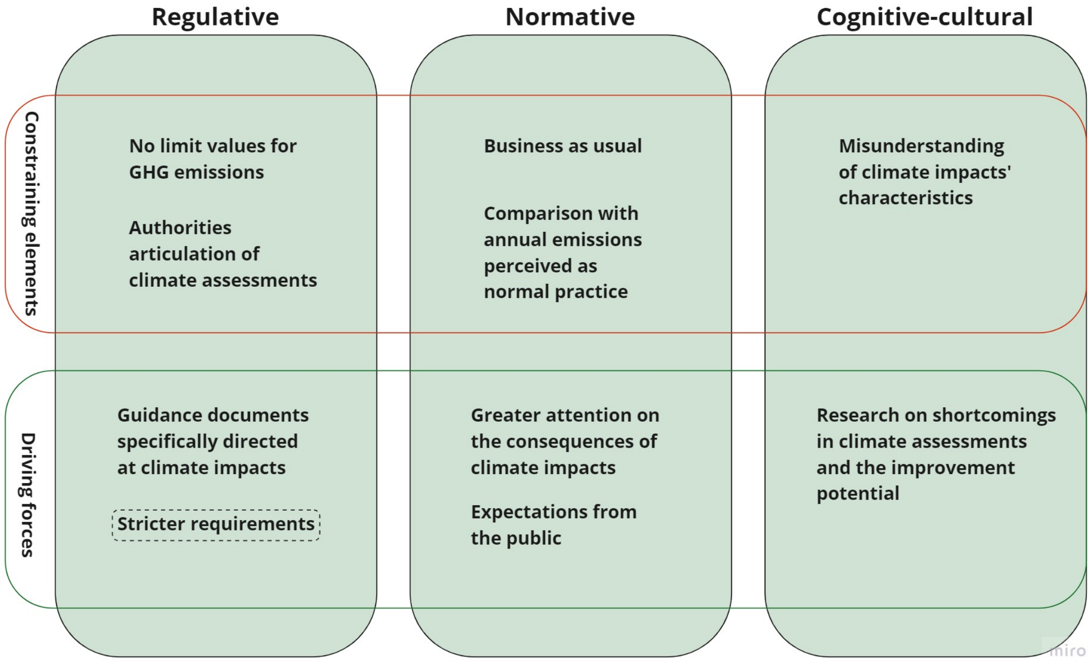


Figure 7.1. Elements related to the three institutional pillars (regulative, normative, and cognitive-cultural) according to whether they contribute to constraining the practice or driving it forward. Stippled box = element with potential to drive the practice forward but which is not yet occurring

Overall, It could be argued that the increased attention which is given to the consequences of climate change, and how human activities contribute to these, indicates that change within EA practice is imminent. Furthermore, the fact that change is occurring within other sectors, e.g. the introduction of the aforementioned threshold values for CO_2 emissions of buildings, also supports this argument. Based on these notions, the practice is perceived as developing, with several elements pushing for change towards more adequate assessments of GHG emission impacts.

8 Conclusion

Human induced GHG emissions have unequivocally caused climate changes in every region of the globe and will continue to do so. Thus, the climate situation is considered critical, and action is needed. Several stakeholders have emphasised that EA holds great potential in regards to ensuring that GHG emiss ion impacts are assessed and communicated to decision-makers. Despite of this, scientific publications and governmental evaluations have concluded that there is a need for more systematic and thorough assessments of GHG emission impacts.

LCT is suggested as a potential contribution to GHG emission assessments by guidance documents. Therefore, the potentials of including LCT in Danish GHG emission assessments have been explored by answering the following research question:

How can life cycle thinking contribute to improving assessments of GHG emission impacts in environmental assessment?

In order to guide the research and answer the main research question, three sub-questions were formed and answered.

The **first sub-question** was aimed at gaining an understanding of the current Danish practice of assessing GHG emissions in EA. Based on a survey with 60 Danish EA practitioners, it is concluded that EA practitioners generally have a negative perception of the quality of GHG emission assessments, and the preciseness of methods applied. This correlates with the fact that practitioners also experience some degree of pressure/demand for improving the assessment of GHG emissions. Through a text analysis of GHG emission assessments in 51 Danish EIA reports and 51 SEA reports, several shortcomings of the practice were identified: **1)** Life cycle considerations are lacking in GHG emission assessments as it is common practice to include only one life cycle phase (most frequently the operations phase). **2)** Significance determinations lack transparency and GHG emission impacts are generally considered as being either insignificant or minor/small. Furthermore, those that are determined to be significant, are almost exclusively positive impacts. This implies a predisposition to negative GHG emission impacts rarely being taken seriously. **3)** Significance determinations of GHG emission impacts lack a systematic and sufficient approach. Several categories of reference for comparison are applied in determining significance, of which the majority are deemed insufficient, as they represent an attempt at articulating the magnitude of impacts in a way which makes them appear insignificant.

Overall, it can be concluded that the Danish approach to assessing GHG emission impacts is deficient in terms of life cycle perspectives and clear, consistent, and sufficient significance determinations. Hence, the EA practitioners' perception of GHG emission assessments correlates with the actual practice.

The purpose of the **second sub-question** was to identify the potential benefits and limitations of applying LCT for EA purposes, as well as to determine how widely LCA is applied in practice. Through a literature review of 16 articles and interviews with three researchers, it is concluded that the application of LCT for EA purposes has several benefits including the ability to identify environmental hotspots and to rigorously and quantitatively compare alternatives. However, limitations related to required resources and competences of practitioners are also emphasised. Generally, there is a lack of studies exploring the integration of LCT in the EA practice, even though the application is recommended by EA guidance documents. Based on the survey results, practitioners lack knowledge of LCA as a tool, and experience with its application. However, it appears that many EA practitioners believe that LCA (or other data-driven approaches) can and should be used in assessing GHG emission impacts. The absence of pressure/demand to do so could imply that approaches to LCA implementation, and the benefits of doing so, are not sufficiently established.

To explore the extent of LCA application in Danish EA practice, a text analysis of 276 recent Danish EA reports was conducted. Based on the results, it can be concluded that LCA is rarely applied for GHG emission assessments. Few reports reference findings of existing LCA studies, while only five apply LCA as an impact assessment tool. However, a commonality between the assessments where LCA is applied is that the phase 'demolition and waste processing' is excluded without any justification. Based on these results, it can be concluded that including LCA is not an integrated part of EA practice.

The aim of the **third and final sub-question** is to explore how LCT can be applied in GHG emission assessments, based on the conclusions of the the previous sub-questions. Regarding the inclusion of life cycle phases, two EIA reports were selected as cases; a road upgrade project and a wastewater treatment plant expansion project. The purpose of this was to exemplify the potentials of LCT application in an actual EA context.

For both cases, the application of LCT demonstrated that assessments of GHG emission impacts include a very limited part of potential life cycle phases and activities. Furthermore, the LCA modelling of the two systems also revealed that the most significant activities were not included in the assessments of GHG emissions. In conclusion, the application of LCT emphasised that consideration of all life cycle phases and activities is vital in ensuring that potential GHG emission impacts of PPPs are sufficiently accounted for. However, it is also evident that the outcome of LCA calculations depends heavily on data availability and assumptions, which may or may not be an issue in EA practice.

In regards to determination of significance, it is argued that LCT can provide more well-founded assessments of GHG emission impacts, thus contributing to more adequate significance determinations. Hotspot analysis contributes to providing direction, as it identifies which life cycle phases and activities induce the greatest GHG emission impacts. Furthermore, LCA calculations in which similar FUs are applied enable the comparison of both different PPPs and of alternatives. Overall, however, LCT is not regarded as a stand-alone solution, as the issue of sufficient significance determination references still remains. Therefore, it is proposed that legally enforced threshold values for GHG emissions are implemented into EA practice. The values should be consistent with the Danish climate goal of reducing GHG emissions by 70% before 2030. Furthermore they should be specific to different PPP types, and would require LCA in order to account for emissions throughout life cycles.

In conclusion, based on the research undertaken for this thesis, LCT can contribute to improving assessments of GHG emissions in the following ways:

- LCT contributes to gaining a comprehensive understanding of the system, thus reducing the risk of overlooking potentially relevant activities throughout the life cycle of the PPP.
- Hotspot analysis is an effective means of identifying the most significant life cycle phases and activities, which is a valuable asset in the screening and scoping phases of EA.
- Overall, LCT contributes to more well-founded assessments, thus supporting more accurate determinations of significance.
- Because LCT is not considered a stand-alone solution, GHG emission thresholds are offered as a means of providing a reference for determining impact significance.

Having concluded upon the main research question, a view upon the practice of assessing GHG emission impacts in EA is presented. The discussion is based on institutional theory (institutional pillars), and aims to comment on the existing practice, as well as the direction in which the practice is developing. Overall, it can be concluded that various elements within the three institutional pillars can contribute to constraining and developing the practice. Within the regulative pillar, the absence of threshold values and the actions of authorities constrain the practice, while guidance documents and stricter requirements (potentially) push for change. The constraining normative elements include 'business as usual' approaches, and the application of insufficient reference categories, while the driving forces include increased attention to GHG emission impacts and expectations from the public. Finally, misunderstandings of GHG emissions constrain development within the cognitive-cultural pillar, while the findings research can be considered as driving the change. Overall, the practice of GHG emissions assessment is perceived as developing, with several elements pushing for change towards more adequate assessments.

Future research should look into how LCT might be implemented in EA practice and thereby examine what is required in order to operationalize it. The research should demonstrate which aspects actually pose as obstacles and which offer the most opportunities for accommodating GHG emissions. In order to improve the practice, future research could additionally look at which degrees of LCT and LCA are required in particular EA circumstances, as well as which PPP types and situations require quantification and which do not.

9 Perspectives

According to the conclusions of the research done for this thesis, current EA practice does not result in sufficient assessments of GHG emission impacts. This may be explained by a multitude of different factors, which are also explored throughout this report. However, this also raises the question of whether EA procedures possess the means to adequately accommodate these impacts. The Danish law on environmental assessment states that:

> *"The purpose of an environmental assessment is to consider the anticipated significant environmental impacts, including (...) climatic conditions (...), while involving the public as early as possible and* ***prior to*** *the authority making a decision on the plan, program, or project's adoption"* [The Danish Ministry of Environment, 2021].

Thus, it is emphasised that the purpose of EA is to ensure environmental concerns are accounted for and taken into consideration prior to decision-making. However, it can be argued that the decision to implement a proposed PPP is made well before the (formal) EA process is initiated. The expansion of the port of Aarhus (mentioned in chapter 7) is an example hereof. It is reasonable to believe that such a project can only be realised if there is sufficient political will, and so the decision to implement becomes an integral component of the project as a whole. In terms of GHG emissions, it may be argued that this practice obstructs the use of the most effective reduction measure, i.e. that realisation of the project does not occur. According to IEMA [2022], the opportunity to affect project GHG emissions is greatest during the early stages of planning, while the costs hereof are also at their lowest (cf. figure 9.1).

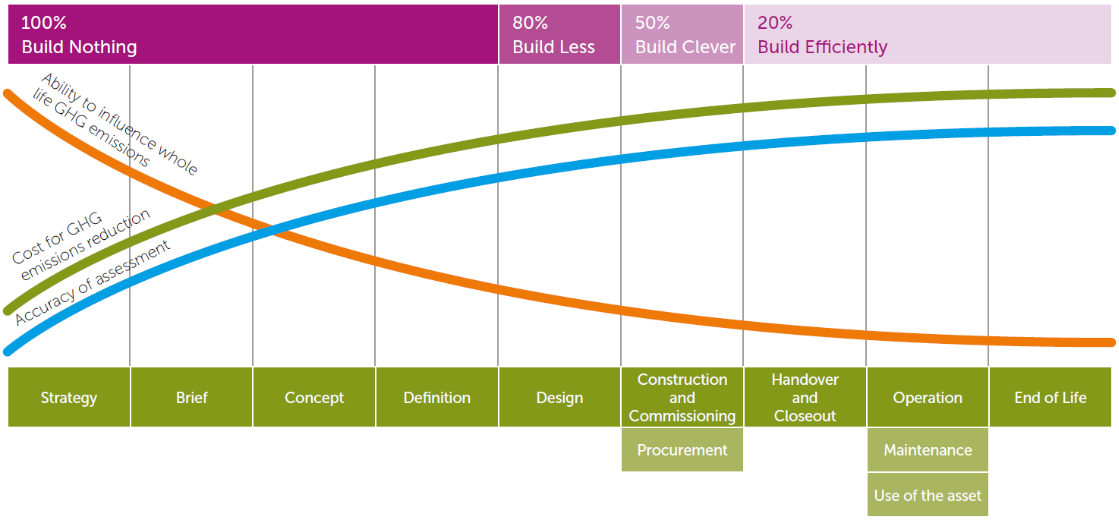


Figure 9.1. The figure illustrates a timeline for project planning. Is indicated, the ability to influence GHG emissions declines over time, while accuracy of the assessments rises [IEMA, 2022].

The key point, based on these acknowledgements, is that GHG emission reduction should be prioritised as early as possible. This notion is also supported by the EU Guidance on Integrating Climate Change and Biodiversity into Environmental Impact Assessment, stating that:

> *"many alternatives and mitigation measures important from the point of view of biodiversity and climate change should be addressed at strategic level"* [The European Union, 2013a,p.35].

However, as the figure also illustrates, the accuracy of assessments increases over time, creating a paradox between influence and accuracy of assessments. This could explain why EA is ineffective when it comes to imposing change - the procedure is started at an inopportune time. In conclusion, the claim could be made that planning practice is impeding EA in fulfilling its purpose.

Thus, if it is recognised that the current EA procedure is insufficient, the challenge of accounting for GHG emissions prior to PPP approval persists. In this regard, it is evident that most developments induce GHG emissions in some shape or form, which can only be mitigated to some extent. Therefore, an alternative approach would be to decide upon how distribute GHG emissions at a societal level, i.e. through strategic planning initiatives. The approach can be compared to quota systems, and would allow decision makers to prioritise activities (developments within different sectors), while ensuring that "GHG quotas" are kept.

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Urland, 2021. Windturbines at Ulkær moor.

A Appendix

A.1 Literature review

Table A.1. List of scientific literature found using literature review

Title	Country	Aim of the study	Conclusion	Reference
Integrating life cycle assessment into the framework of environmental impact assessment for urban systems: Framework and case study of Masdar city, Abu Dhabi	United Arab Emirates (Abu Dhabi)	To refine the framework for integrating LCA into the EIA-process and to apply the framework in a case example of urban expansion. The study focus upon the scope and assessment phases of the tools and are limited to the impact types human health, ecosystmes, and resources	The framework presented in the study outlines how LCA could be integrated into various steps of the EIA procedure. Main limitations of and LCA-EIA integration are lack of data which leads to assumptions, time and data insensitivity	[Madhu and Pauliuk, 2019]
Life Cycle Assessment (LCA) in Environmental Impact Assessment (EIA): principles and practical implications for industrial projects	Poland	To present an alternative approach for the assessment of the environmental impacts from industrial projects by integrating LCA techniques into the EIA procedure	Integrating LCA techniques into the EIA process (including scoping, consideration of alternatives, and assessment of significance of environmental impacts) can enhance the EIA's quality and completeness and give a more in-depth evaluation of environmental impacts	[Rybaczewska-Błażejowska and Palekhov, 2018]
Analysis of strategic environmental assessment in Taiwan energy policy and potential for integration with life cycle assessment	Taiwan	*"This research aims to develop an innovative process to integrate LCA into SEA. Using the case study of Taiwan's energy policy, we attempt to explore the potential for involving LCA in each step of SEA, as well as the effectiveness of integrating the two processes"*	*"SEA represents a platform for facilitating connection between LCA an policy making. LCA has shown its potential to allow more active interaction with alternative planning and scoping in the future.The main limitations involve the clarification of goals related to alternative planning, scoping, and public participation."*	[yu Wu and wen Ma, 2018]
An innovative implementation of LCA within the EIA procedure: Lessons learned from two Wastewater Treatment Plant case studies	France	To propose a comprehensive operational methodology for implementing an LCA within an EIA	EIA steps that can benefit from LCA: (a) the environmental comparison of alternatives, (b) the identification of key impacts, (c) the impact assessment, and (d) the impact of mitigation measures. Comparison between EIA results with and without LCA: EIAs with or without inputs from LCA, led to different conclusions. LCA perspectives showed that other less polluting technologies could have been chosen	[Larrey-Lassalle et al., 2017]
Environmental impact assessment as a complement of life cycle assessment. Case study: Upgrading of biogas	Argentina	The aim of the study is to present a comparison between an EIA and a LCA using a case study of a biogas upgrading project	Instead of applying the different tools separately they should instead be used simultaneously in order to complement each other. *"From the strengths and weaknesses of each tool, it is inferred that the EIA is a procedure that can complement the LCA"*	[Morero et al., 2015]

Table A.1 – continued from previous page

Title	Country	Aim of the study	Conclusion	Reference
Life Cycle Assessment in environmental impact assessments of industrial projects: towards the improvement	Lithuania	To demonstrate how LCA can complement the EIA process for an industrial project	The application of the integrated LCA and EIA framework makes it possible to identify the life cycle stage responsible for the biggest environmental impact on various environmental factors (identifying hot-spots), and helps to find more environmental friendly alternatives	[Židonienė and Kruopienė, 2015]
Life cycle thinking in impact assessment—Current practice and LCA gains	Denmark	To emphasise the gains of applying LCA to IA practice	*"LCA can, indeed, widen the perspective of IA practice. However, this is not through the introduction of LCT per se, since such perspective already exists in thorough IAs. Instead, it is by helping IAs to be more explicit on their embedded function and by facilitating a more rigorous, impact-oriented and quantitative assessment practice in regard to resource use."*	[Bidstrup, 2015]
Life Cycle Assessment in spatial planning – A procedure for addressing systemic impacts	Denmark	To present a LCA procedure which can be operationalised in SEAs of various types of planning	The 'procedure' performed well when applied to Danish aggregate planning: new knowledge on how to identify and address key systemic impacts, and helped to highlight trade-offs regarding mitigation. However, applying LCA in SEA may be a challenge for spatial planners as it entails a change in the assessment paradigm	[Bidstup et al., 2015]
Adapting the LCA framework to environmental assessment in land planning	France	To propose a methodological framework for applying LCA to the required stages of environmental assessment in land planning	There is a need for formalized tools which can contribute with quantitative indicators when assessing a territory. Identifies four major methodological challenges in order to obtain useful indicators for land planning: definition of functional unit, boundary selection, data collection, and refinement of the life cycle impact assessment phase. Especially the goal and scope definition phase needs adaptation	[Loiseau et al., 2013]
Life cycle assessment as an analytical tool in strategic environmental assessment. Lessons learned from a case study on municipal energy planning in Sweden	Sweden	To describe the use of LCA as an analytical tool for environmental assessment in SEA, with focus on methodology and practical experiences.	LCA works well in the context of SEA in local energy planning and can contribute to improved practice by providing a wide systems perspective and systematic framework. However, LCA cannot address all required aspects, and therefore needs to be complemented by other tools. Overall, it resulted in an innovative approach to designing the scope of the environmental assessment and defining and assessing alternatives	[Björklund, 2012]

Table A.1 – continued from previous page

Title	Country	Aim of the study	Conclusion	Reference
Options for broadening and deepening the LCA approaches		*"This paper explores the potential options for deepening and broadening the LCA methodologies beyond the current ISO framework for improved sustainability analysis. By investigating several environmental, economic and social assessment methods, the paper suggests some options for incorporating (parts of) other methods or combining with other methods for broadening and deepening the LCA".*	*"Combinations of LCA with some of these methods can be used to provide a more comprehensive picture. For instance, at project level, EIA can complement LCA by providing information on local, site-specific aspects and vice versa (LCA providing information on global impacts)"*	[Jeswani et al., 2010]
Should Life Cycle Assessment be part of the Environmental Impact Assessment? Case study: EIA of CO2 Capture and Storage in Canada	Canada	Based on a review of Canadian EIA-guidelines this study seeks to suggest how the LCA tool can be applied for EIA studies	Concludes that the LCA tool is beneficial to apply in EIA's of carbon capture and storage projects	[Manuilova et al., 2009]
Using Life Cycle Assessment (LCA) as a Tool to Enhance Environmental Impact Assessments (EIA)	Canada	To develop and apply a methodology that can improve the EIA process for major industrial projects by integrating LCA	*"when EIA metrics are combined with LCA metrics, a more thorough comparison of design alternatives can be performed."*	[Cornejo et al., 2005]
Strategic Environmental Assessment methodologies - applications within the energy sector		To present analytical tools and discuss their relation to SEA, including methods for future studies, Life Cycle Assessment, Risk Assessment, Economic Valuation and Multi-Attribute Approaches. A framework for the integration of some analytical tools in the SEA process is suggested.	It is found that several existing tools can contribute, either by focusing mainly on the identification and modelling of environmental change (e.g. LCA, RA, future studies) or by focusing mainly on the valuation stage (e.g. MAA methods, economic valuation methods, surveys)	[Finnveden et al., 2003]
Life cycle assessment as a tool in environmental impact assessment	Netherlands	Based on former literature which argues that there is an essential difference between EIA and LCA, this article wish to show that the difference is not as great as previously perceived	This paper has shown that there is no fundamental contradiction between EIA and LCA. Therefore will is an application of both approaches considered to be beneficial in terms of conducting a thorough impact assessment. The use of LCA in EIA is especially beneficially when comparing project alternatives	[Tukker, 2000]

Table A.1 – continued from previous page

Title	Country	Aim of the study	Conclusion	Reference
Environmental assessment of a territory: An overview of existing tools and methods	France	To review and discuss the existing tools and methods used in strategic environmental assessment of territories (HERA, The EF, MFA, SFA, PIOT, ENA, Exergy, Emergy and LCA).	Each of the existing tools have strengths and weaknesses, yet none can be used to perform a holistic assessment of territories. A methodology comprised of several supporting tools may be a solution. LCA emerges as a promising framework for the environmental assessment of a territory, as it enables integration of resource consumption accounting, emissions, and potential environmental impacts, while avoiding burden shifting. However, several adaptations are needed so as to better address environmental issues such as biodiversity, land use, and water use, and to improve characterisation of site-specific impacts.	[Loiseau et al., 2012]

A.2 Survey questions

Questions	Predefined responses
Climate	
Have you ever been part of an environmental assessment process where climate was included as one of the environmental factors assessed?	Yes, No, Don't know
How do you perceive the quality of climate change impact assessment?	Very poor, Poor, Medium, Good, Very good, Don't know
Do you experience a pressure/demand for improving climate change impact assessments?	None at all, Minor degree, Some degree, High degree, Very high degree, Don't know
Do you know methods for assessing climate impacts?	Yes, No, Don't know
To what degree do you think that the methods used to assess climate change impacts create a true estimate of the impact of the plan, program or project?	Very poor, Poor, Medium, Good, Very good, Don't know
Life cycle assessment	
Do you have knowledge of the life cycle assessment tool?	None at all, Minor degree, Some degree, High degree, Very high degree
Have you used life cycle assessment of the specific plan, program or project to assess climate impacts?	None at all, Minor degree, Some degree, High degree, Very high degree
Do you see a need to make assessments of climate impacts more data-driven/quantitative?	None at all, Minor degree, Some degree, High degree, Very high degree
To what degree do you experience that LCA is applied as a tool to assess climate impacts?	None at all, Minor degree, Some degree, High degree, Very high degree
Do you experience a pressure/demand for including life cycle perspectives in the assessment of climate impacts?	None at all, Minor degree, Some degree, High degree, Very high degree

Table A.2. Survey questions related to climate and LCA in EA processes

A.3 Interview guide

Theme	Question
Presentation	Who are we
	What is the purpose of the interview
Formalities	Can we record the interview?
	Can we quote you by name? And would you want the quotes for inspection?
Presentation of respondent	Can you present yourself, including your job title and experiences?
Interview Questions	
The purpose of the article	Why did you choose to study LCA application for environmental assessment? (what motivated you?) • What was your goal? • Did you obtain the expected results?
Research results	Based on your study, what do you consider as the greatest potentials/limitations for integrating LCA into EA? • How can one accommodate the challenges?
	What is the difference between integrating LCA into EIA compared to SEA?
LCA method	LCA can be quite resource intensive. Do you see any potentials for shaping a methodology that is less comprehensive? • How would this be done?
	Are there any alternatives to LCA for accommodating the weakness of EIA/SEA procedure?
Research vs. practice	Do you see a gap between the findings of research and EA practice? • Why is this the case?

	Do you think research has influenced practice? • Has anything happened since your article was published? Regarding practice/research?
	What would you propose as the main drivers for implementing LCA in EA practice?
Future research	Is it your understanding that further studies are required for the subject (if yes, what?)

Table A.3. Interview guide for Pyrène Larrey-Lassalle, Anna Björklund, and Morten Bidstrup

A.4 Distribution of PPP types

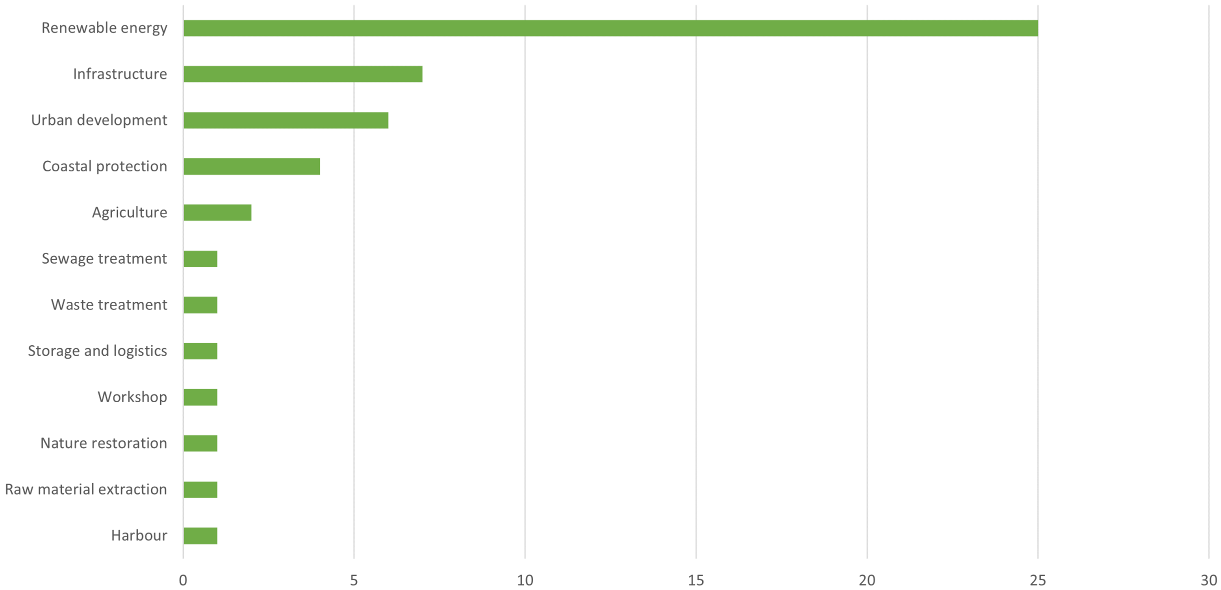

Figure A.1. Distribution of EIA report types.

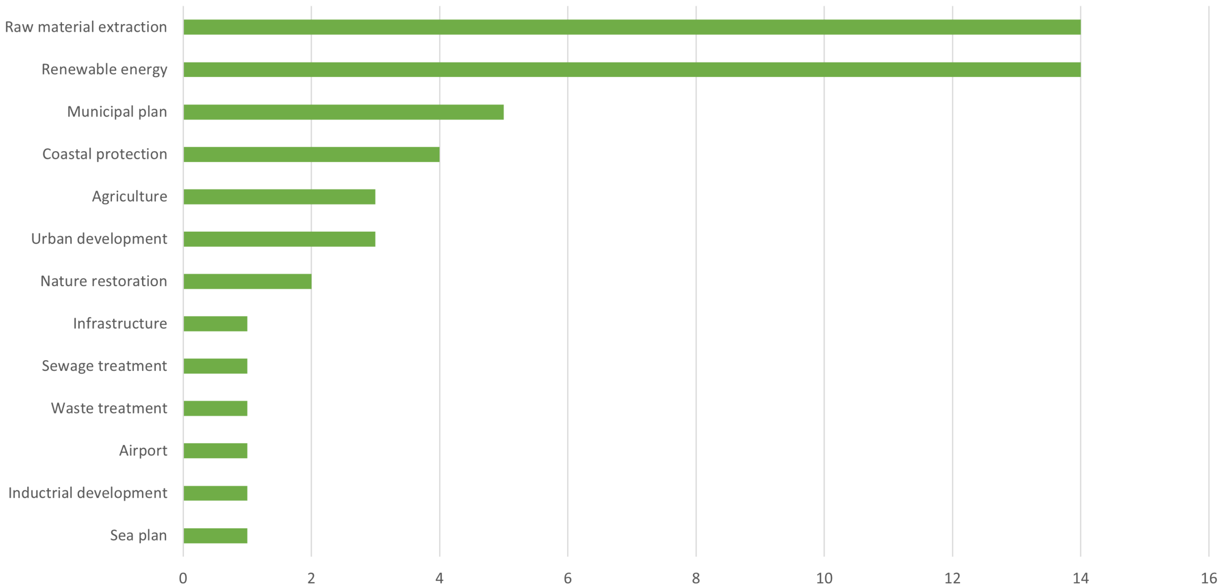

Figure A.2. Distribution of SEA report types.