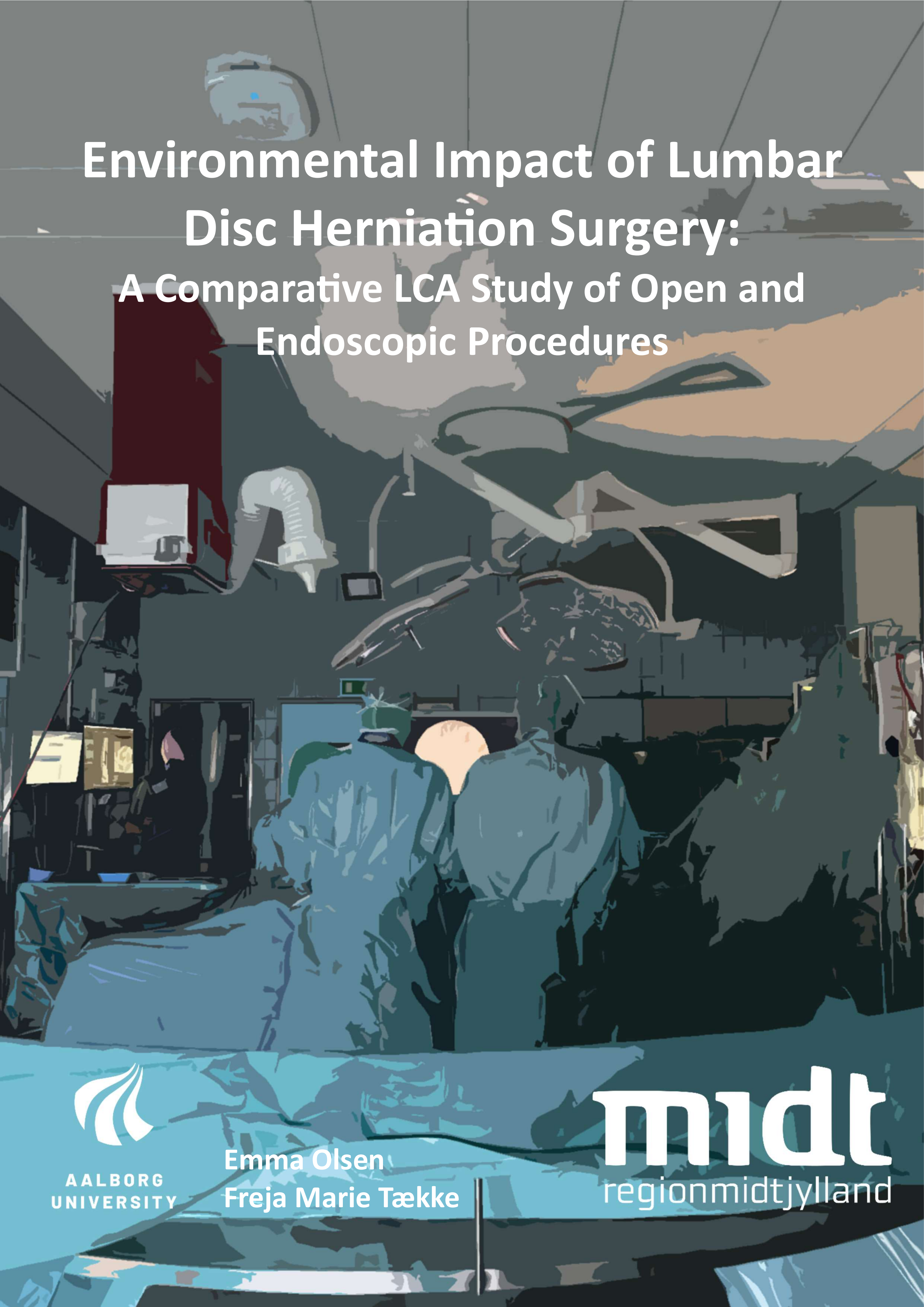

Environmental Impact of Lumbar Disc Herniation Surgery:

A Comparative LCA Study of Open and Endoscopic Procedures

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AALBORG UNIVERSITY

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The image for the front page was taken during the observation at Aalborg University Hospital (AaUH).

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Synopsis:

This study explores a comparative Life Cycle Assessment of two surgical procedures for treating lumbar disc herniation; open and endoscopic procedure. The study seeks to answer the research question: **"How can the environmental impact of a lumbar disc herniation surgical procedure be assessed and reduced to support sustainable healthcare?"**.The study is based on a case from Aarhus University Hospital and conducted in collaboration with healthcare professionals.
Surgical procedures are among the most resource-intensive activities in the healthcare sector. This study quantifies and compares the environmental impact using a consequential LCA approach along with EXIOBASE and hybrid processes as background data. The overall findings suggest that endoscopic procedure generally leads to a lower environmental impact, mainly due to reduced surgery duration and shorter admissions.
The study includes science-theoretical reflections on the LCA practitioner's role and the importance of transparent modelling. Overall, the thesis supports integrating environmental considerations into clinical decision making and highlights opportunities for more sustainable healthcare practices.

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Abstract

This master's thesis presents a comparative Life Cycle Assessment of two surgical procedures for treating lumbar disc herniation; open and endoscopic procedure. The study is conducted in collaboration with Aarhus University Hospital (AUH), Aalborg University Hospital (AaUH), and the Center of Sustainable Hospitals in the Central Denmark Region. It aims to quantify and compare the environmental impact of each procedure across their individual patient pathway.

Using a consequential LCA approach along with EXIOBASE and hybrid processes, the study identifies contributing factors such as single use equipment, energy consumption, and admission expenditures. The results conclude that the endoscopic procedure generally have a lower environmental impact compared to the open procedure, primarily due to reduced admission and surgery duration, resulting in reduction in consumption such as electricity use. However, factors such as patient suitability and learning curves for surgical staff in the conversion of the endoscopic procedure are important to consider before a full implementation.

The thesis reflects on the epistemological and ontological assumptions in LCA modelling, as well as the communication challenges between system-world modelling and life-world in clinical practice. The findings contribute to the broader goal of integrating sustainability into healthcare decision-making and underscore the need for data driven but context sensitive approaches.

Foreword

This master's thesis marks the culmination of our studies in Environmental Management and Sustainability Science at Aalborg University. The process of writing this thesis has been both challenging and rewarding, and we are grateful to all who have supported us throughout our study.

First and foremost, we would like to thank our supervisors, Jannick Schmidt and Lasse Krogh Poulsen, for their invaluable guidance, critical insights, and continuous support throughout the project. Their expertise within Life Cycle Assessment and environmental modelling has been instrumental in shaping this thesis.

We also owe a special thanks to Gorm von Oettingen, Claus Ørum, and Carsten Reidies Bjarkam for their generous collaboration, professional input, and for granting us access to clinical and technical knowledge at Aarhus University Hospital and Aalborg University Hospital. Their contributions significantly enriched the practical relevance and depth of this study.

In addition, we would like to express our sincere gratitude to the Center for Sustainable Hospitals, particularly Rasmus Revsbeck, Lærke Dahl Klausen, and Dorte Blegbrønd Gosvig, for their encouragement, helpful discussions, and for making this collaboration possible. Their work and commitment to promoting sustainable initiatives in the healthcare sector have been a great source of inspiration throughout our project.

Lastly, we want to thank all the healthcare professionals who welcomed us into their daily routines and provided vital perspectives during observations and conversations. Their openness has helped us bridge theory with practice.

Aalborg, May 2025

Emma Olsen & Freja Marie Tække

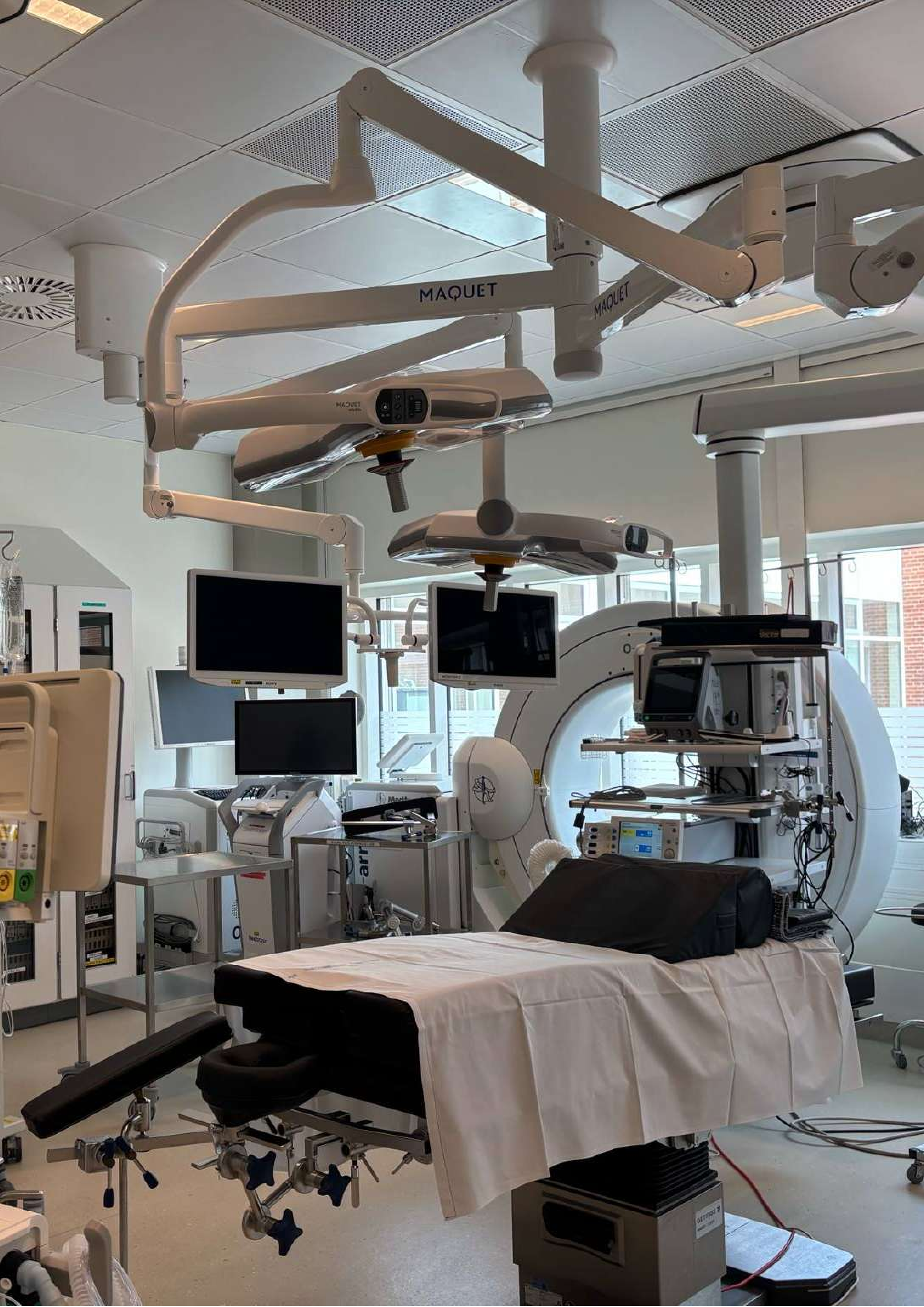
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Table of Contents

Terminology

The study includes several abbreviations and key terms throughout, which are further elaborated and clarified below.

Abbreviations

- **AUH** Aarhus University Hospital
- **AaUH** Aalborg University Hospital
- **CO_2-eq** Carbon Dioxide Equivalent
- **GHG** Greenhouse Gas
- **IO** Input-output
- **ISO** International Organisation for Standardisation
- **LCA** Life Cycle Assessment
- **LCI** Life Cycle Inventory Analysis
- **LCIA** Life Cycle Impact Assessment
- **UNSPSC** United Nations Standard Products and Service Code

Terms

- **Functional Unit**: Quantified performance of a product system for use as a reference unit (International Standard, 2006).
- **Impact Category**: Class representing environmental issues of concern to which life cycle inventory analysis results may be assigned (International Standard, 2006).
- **Life Cycle Assessment**: Compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle (International Standard, 2006).
- **Life Cycle Impact Assessment**: Phase of life cycle assessment aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts for a product system throughout the life cycle of the product (International Standard, 2006).
- **Life Cycle Inventory Analysis**: Phase of life cycle assessment involving the compilation and quantification of inputs and outputs for a product throughout its life cycle (International Standard, 2006).
- **Patient Pathway:** A patient pathway refers to all the stages a patient experiences in the management of his or her disease, from pre-diagnosis to palliative care (Alcimed, 2025).

- **Product System**: Collection of unit processes with elementary and product flows, performing one or more defined functions, and which models the life cycle of a product (International Standard, 2006).
- **Sensitivity Analaysis**: Systematic procedures for estimating the effects of the choices made regarding methods and data on the outcome of a study (International Standard, 2006).
- **System Boundary**: Set of criteria specifying which unit processes are part of a product system (International Standard, 2006).

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1 Introduction

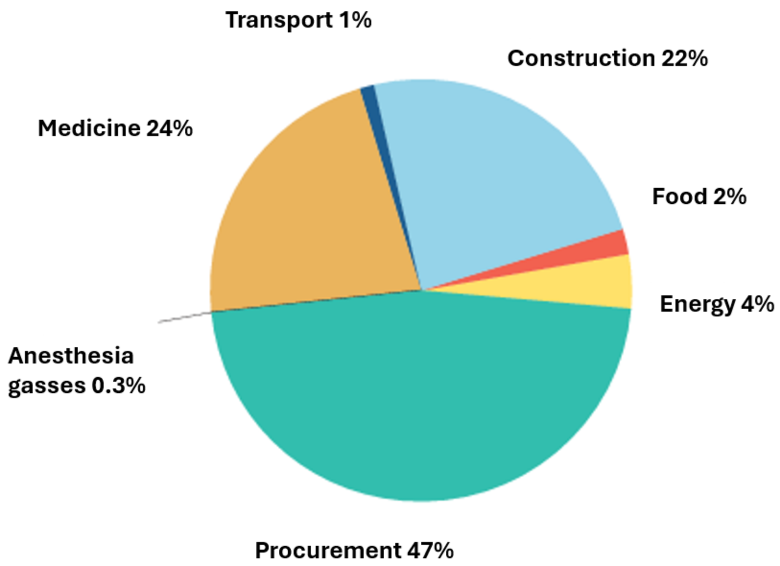
Climate change is recognised as one of the most important global challenges of the 21^{s}t century. According to the World Health Organisation, it contributes to approximately 250,000 deaths per year through increased air pollution, extreme weather, diseases, and hunger (World Health Organisation, 2025).

To mitigate these impacts, global climate initiatives aim to reduce the greenhouse gas (GHG) emissions driving climate change (Eurpean Union, 2025). In 2021, the European Union (EU) adopted *the European Climate Law*, which commits member states to reduce their GHG emissions by at least 55% by 2030 compared to 1990 levels and achieve climate neutrality by 2050 (European Union, 2021). As a member of the EU, Denmark is legally obligated to meet these targets (Jensen, 2025).

The healthcare sector constitutes a significant role in Denmark's total GHG emissions, contributing with approximately 6% of the national GHG emissions (Danske Regioner, 2023). A study by Schmidt and Merciai (2023), estimates that "Health and social work services" are responsible for 6.1 million tonnes of CO_2-eq — approximately 8% of the country's total GHG emissions. The public Danish healthcare system is managed by five regions and the procurement organisation Amgros, a Danish procurement company for the Danish hospitals (Amgros, 2025). The five regions and Amgros are therefore central drivers to achieving emission reductions (Danske Regioner, 2025a).

In 2023, the Danish Regions launched a cross-regional climate strategy aimed at supporting these goals. In 2022, regional emissions concluded approximately 3.3 million tonnes of CO_2-eq. As shown in Figure 1.1, procurement is the largest contributor, followed by pharmaceuticals and construction activities (Danske Regioner, 2023).

To support the national strategy, the Central Denmark Region has launched a sustainability initiative led by the Center for Sustainable Hospitals. A core objective is to reduce the environmental impact of surgical procedures, particularly by transitioning from single use to reusable medical equipment (Center for Bæredygtige Hospitaler, 2025).



Figur 1.1. Distribution of Regional CO_2 emissions (Danske Regioner, 2023)

Data collection and monitoring are key tasks in this strategy, as high-quality data is essential to improve transparency, supporting informed decision making, and guiding innovation toward more sustainable practices (Danske Regioner, 2023).

To contribute to this effort, there is a growing need for detailed environmental data related to surgeries. Surgical procedures consume substantial amounts of medical equipment, pharmaceuticals, energy, and water. This study therefore investigates the GHG emissions associated with patient pathways for treatment of lumbar disc herniation, by open procedure or endoscopic procedure, using Life Cycle Assessment as a methodological tool.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Case Study 2

This chapter presents a case study focused on assessing the environmental impact of a patient pathway for the treatment of lumbar disc herniation. The study is situated in the Department of Brain and Spine Surgery at Aarhus University Hospital (AUH) and compares two surgical procedures used as treatment for the same condition; open and endoscopic procedure. The case was selected based on its clinical relevance and potential for broader application across the Danish healthcare system and its other regions.

2.1 Case Description & Collaboration

The study is carried out in collaboration with key stakeholders:

- Gorm von Oettingen, Chief of Brain and Spine Surgery at AUH
- Claus Ørum, Function Manager in the Department of Supply and Service and project manager of the SupplyAID inventory database
- Carsten Reidies Bjarkam, Chief of Brain and Spine Surgery at Aalborg University Hospital (AaUH), where endoscopic procedures have been implemented since 2021

The selected case focuses on lumbar disc herniation surgery, a high-volume surgery performed frequently in hospitals across Denmark. According to Oettingen, its prevalence makes it a particularly relevant candidate for environmental impact assessment, as data availability at AUH is high and findings can be applicable beyond a single institution (Appendix A). Furthermore, the existence of two distinct surgical procedures; open and endoscopic, provides a meaningful comparison that can inform both clinical and sustainability decisions.

The case is not intended to serve as a general baseline for all surgeries but rather as a focused comparison within a specific clinical context.

2.1.1 Department for Brain & Spine Surgery

The Department of Brain and Spine Surgery at AUH is divided into two units: a clinical department and a ward. The clinic is responsible for diagnosis and treatment of conditions related to the cranium, brain, spine, and associated nerves. Patients receive consultations and undergo scans, blood tests, or other examinations as needed here. Depending on the complexity of the surgery, patients are discharged the same day or admitted to the ward for postoperative care. During admission, they receive monitoring, pain management, and rehabilitation support to ensure a safe recovery process and transition post surgery.

2.1.2 Treatment of Lumbar Disc Herniation

Surgical treatment of lumbar disc herniation can be performed using either *open procedure* or *endoscopic procedure*. AUH currently perform the open procedure, while AaUH has adopted the endoscopic procedure. These techniques differ significantly in their degree of invasiveness, equipment requirements, and postoperative recovery.

Open Procedure

The open procedure involves a 10 cm incision in the lower back. Due to its invasive nature and higher risk of infection, this method requires strict hygiene protocols, often relying heavily on single use equipment. The procedure typically lasts between one and three hours, followed by an average hospital admission of 40 hours. Patients are usually unable to work for four to six weeks postsurgery (Appendix A).

AUH is currently outsourcing part of their lumbar disc herniation surgeries in order to meet the demands for treatment. Today they can perform three surgeries per day, and they are investigating if the endoscopic procedure can optimise surgical capacity and increase the number of surgeries to four per day, and thereby reduce outsourcing surgeries to private hospitals.

Endoscopic Procedure

The endoscopic procedure uses an endoscope, which is a slim tube with an integrated camera and light, to access the affected area through a 3-5 cm incision. This technique is less invasive, reduces damage to surrounding tissue, and typically results in less pain and faster recovery. According to Oettingen and Bjarkam, procedure times range from 30 to 90 minutes, and patients are often discharged within a few hours if operated on in the morning or early afternoon (Appendix A and C).

The endoscope must be sterilised between each use, although Oettingen estimates its service life to be ten years, it is assessed to have a service life of eight years, based on conversations with Mads Lænsø Madsen, chief of medico-technical department (Madsen, 2025). Sterilisation procedures are further investigated through visits to AUH's central sterilisation unit, and through an internal calculation tool for sterilisation.

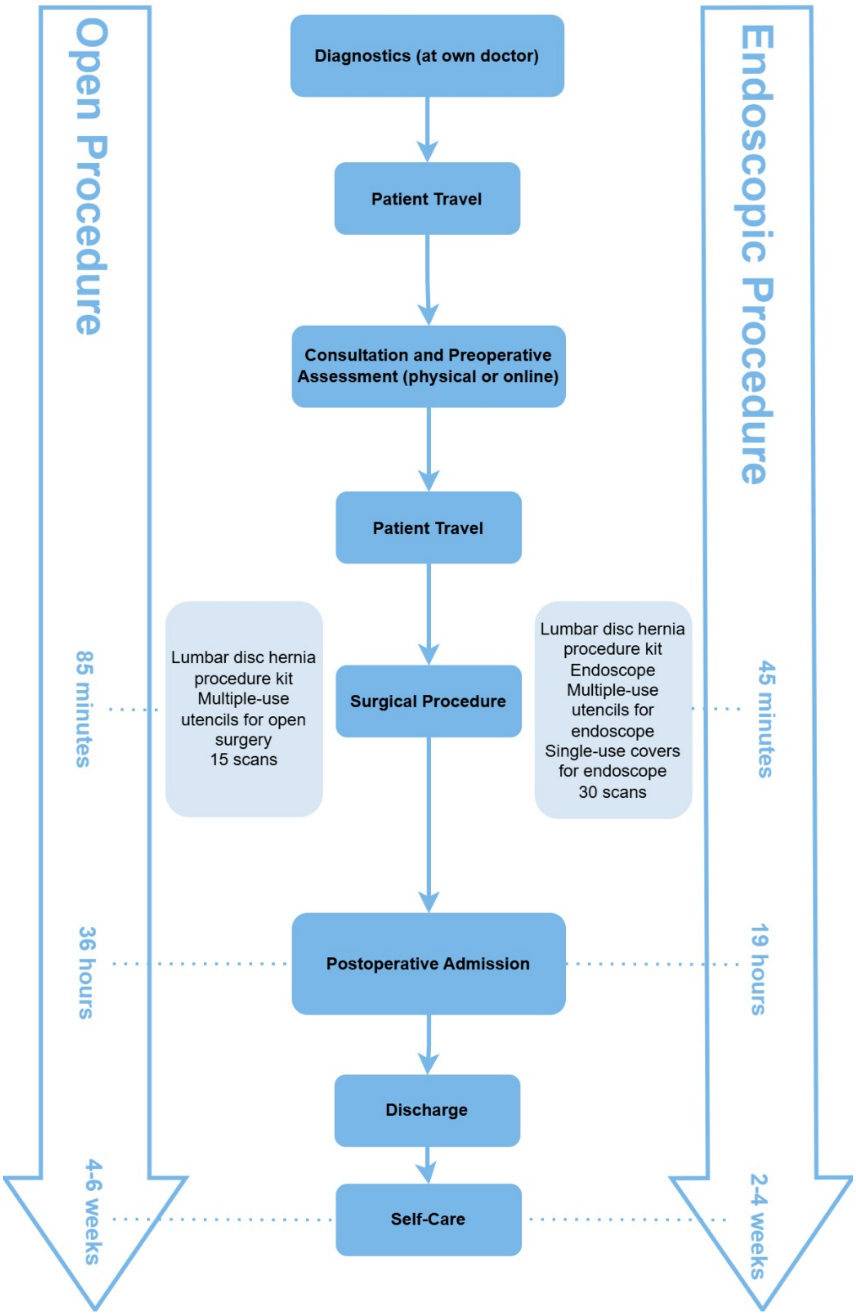
According to Oettingen, the endoscopic procedure could potentially allow for the use of regional or local rather than general anaesthesia. This would reduce anaesthetic use and could increase surgical capacity from three to four procedures per day, see Appendix A. However, Bjarkam notes that awake patients may cause discomfort for both the patient and surgeon during the surgery, and therefore general anaesthesia is still commonly used at AaUH (Appendix D)

Despite its benefits, the endoscopic procedure is not suitable for all patients. Bjarkam estimates that approximately 20% of patients are eligible based on location of the disc and the patient's physical condition. Furthermore, endoscopic procedures may need to be converted to open procedure mid-operation in cases where complications arise or access is more difficult than expected (Appendix C).

The adoption of endoscopic procedure also requires initial investments in equipment and training. Bjarkam reports a steep learning curve and longer surgery durations during the early phase of implementation. Despite this, patient outcomes are promising, with faster recovery and similar re-herniation risks compared to open surgery (Appendix C).

From a systems perspective, Oettingen estimates that the change could be cost-neutral or even cost-saving if regional or local anaesthesia is introduced and outsourcing is reduced. Patients would also return to work faster post operation, offering socioeconomic benefits (Appendix A).

An overview of the pathway for the two procedures and their differences can be seen in Figure 2.1.



Figur 2.1. The patient pathway for both open surgery and endoscopy (own figure).

2.1.3 Potential

This case study explores the hypothesis that converting from open procedure to endoscopic procedure could potentially reduce the environmental impact of lumbar disc herniation treatment.

According to the Danish Spine Database, 61,908 patients underwent spine surgery in 2023, with 61% treated for lumbar pain. Of these, 63% engaged in rehabilitation, which is recommended for all patients post surgery. Within one year, 82% had returned to work, while 18% remained inactive due to pain or complications (Mott, 2024). These numbers underscore the broader implications of surgical efficiency and recovery time, not just for individual health, but also for the healthcare system and socio-economy of Denmark.

To evaluate the environmental impacts of the two surgical procedures, the full patient pathway will be assessed using LCA. This includes preoperative diagnostics, patient transport, surgical procedures, admission, discharge, and rehabilitation, along with all related material and energy consumption.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Research Question 3

This study aims to answer the research question:

How can the environmental impact of a lumbar disc herniation surgical procedures be assessed and reduced to support sustainable healthcare?

This question aims to address the need for sustainable action within the healthcare sector by focusing on two surgical procedures for treating lumbar disc herniation; open procedure and endoscopic procedure. By applying LCA as a methodological tool, the study seeks to quantify and compare the environmental impact of the two procedures and investigate potential impact reductions.

The research question is answered by the analysis of the following two sub-questions:

1. **What are the environmental impact of open procedure and endoscopic procedure?**
2. **How can the environmental impacts of treating lumbar disc herniation be reduced?**

As the purpose of this study focuses mainly on conducting a comparative LCA study of the two surgical procedures, the main part of the effort in this study is focused on conducting the detailed LCAs on the patient pathway for open and endoscopic procedures. The sub-questions presented will highlight the assessment of the environmental impact of the two surgical procedures; open procedure and endoscopic procedure.

The first sub-question will function as a base for conducting the comparative LCA study, following the guidance from the ISO 14040 and 14044. Where the two surgical procedures for lumbar disc herniation are assessed based on their environmental impact. A sensitivity analysis is conducted to test the robustness of the overall LCA results and whether there are uncertainties to take into account when implementing a potential new procedure.

The second sub-question will investigate the opportunity of converting from three to four surgeries per day, as suggested by Oettingen (Appendix A).

The two sub-questions and their respective analyses will contribute to answering the overarching research question which will be further discussed and finally answered by the study's conclusion gathering the conclusions stated throughout the analysis.

The questions posed in this study aim to contribute to supporting healthcare decision making towards enhanced sustainability.


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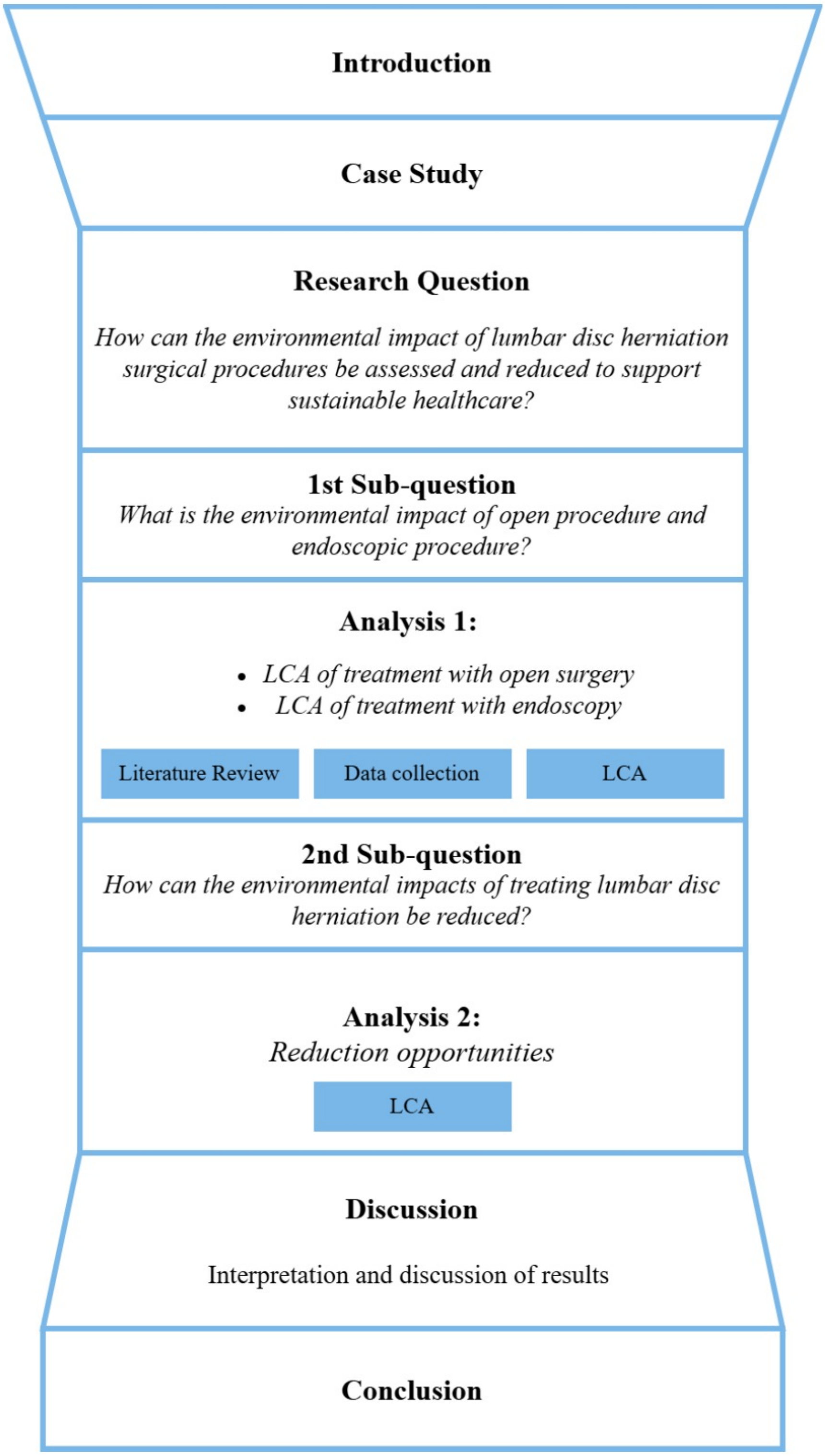
Research Design 4

This chapter introduces the research design of the study, contextualising the theoretical and methodological consideration. The chapter should be understood as an essential guideline to understanding the construction of the study.

The research design of this study is developed to systematically assess the environmental impact of two different surgical procedures for patients with lumbar disc herniation: open procedure and endoscopic procedure. It integrates LCA to explore environmental performance and reduction opportunities for sustainable healthcare.

The research design follows a chronological structure, beginning with a general contextual introduction and case study presenting the setting of what will be investigated. Based on this, the research question and sub-questions are posed defining the structure and what will be analysed in the study. Before analysing the environmental impact of the two surgical procedures and the potential reduction opportunities, a literature review is conducted to establish state-of-the-art on environmental impacts in connection with patient pathways. This will function as a guide throughout the analysis and be compared with this study's findings in order to assess whether environmental impact results from similar cases are comparable or incomparable. The analyses will include empirical data collection and follow the guidelines provided by the ISO standards 14040 and 14044 using a consequential approach. Following the analyses, a discussion will highlight and discuss key elements, findings, and limitations of the study. Lastly, a conclusion will answer the overarching research question, which will be the conclusion that is expected to be brought forward for decision makers within healthcare settings, for example the Department of Brain and Spine Surgery at AUH.

The study's research design can be seen in Figure 4.1.



Figur 4.1. Research design of the study following a chronological order (own figure).

Theoretical Foundation 5

In this chapter, the theoretical foundation is introduced. Firstly, the science-theoretical foundation will contribute as a meta-reflection to this study on how LCA's can be conducted and how the role of the LCA practitioner has an influence on the LCA modelling. In addition, the scientific theoretical foundation covers aspects of epistemology and ontology, hermeneutics, and distinguished understandings of the system world and the life world.

5.1 Science-Theoretical Foundation

When conducting an LCA, the researcher does not only observe and produce data results using a step-by-step guide. Although ISO standards provide a methodological framework, the LCA methodology still leaves room for multiple choices regarding scope, data, and other assumptions. LCA is a modelling tool that requires a range of decisions, assumptions, and interpretations that are shaped by epistemological and ontological standpoints, whether or not implicit or explicit. For instance, when applying LCA to a patient pathway, a challenge is that no patient pathways are identical. Each pathway is shaped by individual human experiences, medical conditions and social context, none of which are uniform. As a result, assumptions must be made about what constitutes to an average patient pathway for the open and endoscopic procedure, in order to model it. These assumptions are not neutral, as they reflect specific epistemological and ontological understandings. From an epistemological perspective, this raises questions about how knowledge is constructed. That includes, what data is valid, and how variability is handled. From an ontological perspective, it concerns what is assumed to exist and be measured, if the pathway is a generalised process or a variable, depending on the patient experience. These assumptions shape the structure and interpretation of the LCA in this study.

The following chapter will explore how ontological and epistemological understandings, hermeneutics, and research paradigms influence the LCA study.

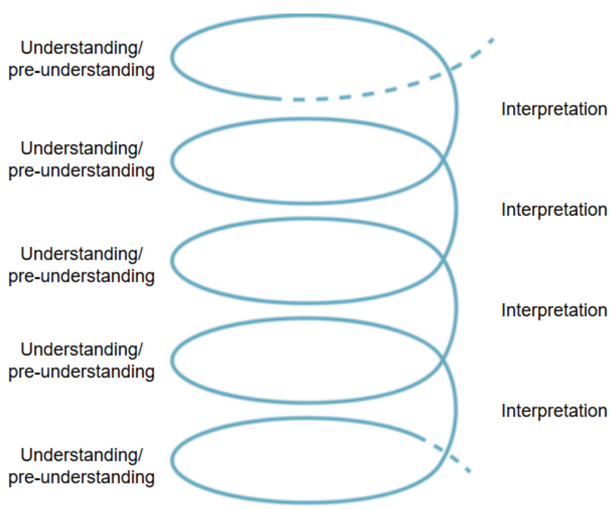
5.1.1 Epistemology & Ontology

Epistemology and ontology are both science-theoretical concepts that are used to understand the world and how knowledge about it is produced. Ontology describes what exists and what can be known about the world, whereas epistemology describes how to gain knowledge (Thurén, 2021).

In the context of LCA it is implicitly assumed that environmental impacts exist in the real world and can be measured. However, which impacts are considered and how they are modelled depending on the framework and the practitioner. This can, for example be whether the world is viewed as a construction of separable units or as a complete and interconnected system. In the context of LCA, this can have an influence on whether the LCA practitioner chooses an attributional (ALCA) or consequential (CLCA) approach for the LCA study. ALCA approach is built on the understanding that the world is static and its processes can be separated and assigned to processes within a defined system. In contrast, CLCA operates under a more dynamic ontology, recognising that systems change in response to the decisions that are made and therefore focuses on causal effects, see Section 6.2.3. The distinction between the ALCA and CLCA can be illustrated with an concrete example from this case study. Oettingen expresses the potential introduction of endoscopic procedure, which could increase the number of surgeries performed per day from three to four (Appendix A). From an ALCA perspective, this change might be interpreted as an environmental improvement, assuming that the endoscopic procedure has a lower impact than the open procedure. However, from a CLCA perspective, the increased capacity could lead to higher overall demand and resource use, also called rebound reflects, resulting in a higher total environmental impact, which would not be captured in a ALCA. This example highlights how the choice of LCA approach reflects different understandings about whether the system is static or dynamic, and whether indirect consequences are considered relevant.

5.1.2 Hermeneutics

Hermeneutics describe how understanding is continually formed through interpretation. It acknowledges that knowledge is not passively observed but actively constructed through communication, observation, and experience (Thurén, 2021), see Figure 5.1.



Figur 5.1. The continuing context between understanding and interpretation in a spiral-model (own model with inspiration from Maintz et al. (2012).)

In the context of this study, hermeneutics become relevant when engaging with healthcare professionals, their view and tacit knowledge about surgical workflows, including use of medical equipment and their decision rationales. These insights cannot be fully captured through data alone, but must be interpreted and integrated through dialogue. Modelling and understanding the environmental impact of a surgery involves engaging in a hermeneutic spiral. This is for example exemplified by the determined amount of x-ray photos taken during a surgery, which is determined through observation in the operating room.Hermeneutics in this context is also a reminder, that LCA is not just a technical task, but also an interpretive one.

5.1.3 Research Paradigm

In research, paradigms influence and define the current view on reality and its underlying assumptions. In connection with LCA, two key paradigms; positivism and constructivism, offer insights of how environmental impacts can be assessed. Understanding the influence of scientific paradigms is crucial for critically assessing the study's methodology and findings, as different paradigms shape both the data collection process and the interpretation of results (Thurén, 2021).

Positivism is based on the assumption that reality exists independently of human perception and can be objectively measured Thurén (2021). In LCA, this perspective suggests that environmental impacts can be quantified through systematic data collection and analysis, making it a recognised and widely applied environmental impact assessment tool. The use of standardised databases, like EXIOBASE, aligns with a positivist approach, as it relies on pre-established models and economic sector classifications to estimate emissions and resource use. However, a complete positivist approach in LCA can cause challenges, as complexities and uncertainties in environmental assessments can be overlooked. LCA attempts to model real-world phenomena, but uncertainties arise from variations in data sources, assumptions about system boundaries, and methodological choices. Therefore, while positivism provides a strong foundation for LCA, it cannot fully eliminate the subjectivity embedded in the study's design and execution. However, some sense of positivism is crucial for LCA studies, as LCA practitioners otherwise will need to take on a critical approach against all data, which would result in time consuming processes to conduct LCAs.

Constructivism differs from positivism by recognising that scientific knowledge is shaped by human choices and interpretation (Thurén, 2021). For example, the choice of system boundary affects which processes and emissions are included or the choice of impact categories. For this specific study, a constructivist perspective is necessary, particularly within the healthcare setting. Medical procedures, equipment use, and hospital workflows introduce specific knowledge that must be embedded in the LCA. For example, assumptions about material consumption, sterilisation procedures, or single use versus reusable instruments must be informed by expert insights, rather than relying solely on generalised input-output data.

An example of the constructivist approach to determining the environmental impact of a surgical procedure is in this study the choice of only looking at one impact category independently, in this case CO_2-emissions. This can be acknowledged as a rather constructivist approach, as it isolates the findings from other impact category results. However, the choice of investigating one isolated impact category can be beneficial in the setting of healthcare, where non-specialists of LCA must understand the results. Here, CO_2-eq serves as a general communicative proxy, that can be received by non-specialists.

5.1.4 System-World & Life-World

The sociologist Jürgen Habermas introduced the concepts of "system-world" and "life-world" to describe the different logics at play in society (Thorgaard, 2024). The system-world represents the formal rules, procedures, and technical rationales. In the context of LCA this can refer to the overall rules and guidelines on LCA modelling. The life-world, on the other hand, refers to practical knowledge, values, and experiences. These two worlds may conflict in decision making. For example, LCA results might indicate that a shift in surgical procedure has a lower environmental impact, but in practice the healthcare professionals may not favour the alternative procedure due to clinical practices. The LCA practitioners can be categorised as having a point of view from a system-world compared to the healthcare professionals in a life-world, where more layers than just the environmental considerations play a crucial role in decision making. For example, when human health is at stake, the social factors which prioritises patient safety, quality of care, and equitable access is naturally prioritised. Environmental and economic factors may be deprioritised if they risk compromising clinical outcomes or the ability of the healthcare system to function effectively.

5.2 The LCA Practitioner's Role

The LCA practitioner constitutes a crucial role in shaping the LCA study through methodological choices and data management. As an LCA practitioner, key aspects such as objectivity, reproducibility, and transparency must be prioritised to ensure the study's credibility and applicability for decision making. Moreover, the LCA practitioner serves as a mediator between disciplines, especially in applied studies. Bridging the gap between environmental science and healthcare requires awareness of different priorities, logics, and languages. Whereas LCA models seek generalisable results, healthcare decision making is often case-based, bound by regulations, patient safety, and available resources. This must be taken into account when communicating LCA results, especially in the aim of influencing practice.

It can be complicated to maintain an objective point of view as modelling choices are an embedded part of conducting LCAs. The modelling choices include e.g. assumptions throughout the modelling and definitions of functional unit and system boundary, etc. The LCA practitioner must be aware of which choices are implicit and explicit in order to ensure transparency in modelling choices. Transparency enables decision makers to understand the limitations and applicability of the results. The modeling should be replicable for other LCA practitioners in order to be a transparent study. LCA is not only an analytical tool, but is also a strategic and political tool forming decision making. The researcher therefore holds a powerful position in determining how the LCA is represented and communicated.

The researcher must involve reflexivity into the process of conducting the study. This covers an ongoing process of awareness of the researcher's own position and how it affects the study. This includes acknowledging potential uncertainties, being open about limitations, and remaining neutral and not manipulating the LCA results to be more favourable or unfavourable. To be a reflective practitioner, it is important to maintain a good argumentation regarding what assumptions are made and why, how the results may be interpreted by other stakeholders, and if the results are as nuanced as the project requires in order to have answer the requirement.

Reflexivity strengthens the legitimacy and ethical integrity of an LCA study and ensures that it can support informed and fair decision making. A reflective LCA study can for example highlight hotspots or uncertainty in its findings, which can be further investigated before a decision is made. It can also contribute to other studies as part of foundational state-of-the-art or as a measuring factor to compare other LCA studies within the same field.

This chapter has illustrated that LCA is not a solely technical practice, but a process shaped by theoretical perspectives and modelling choices. By integrating epistemological, ontological, and hermeneutic considerations, as well as acknowledging the influence of research paradigms, the chapter has highlighted the importance of reflexivity in LCA practice. Recognising the practitioner's role, assumptions and position, enhances transparency, strengthens the scientific integrity of the study, and ultimately supports a more nuanced and informed decision making.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Methodology 6

This chapter outlines the methodological framework applied in this study. The primary method used is LCA, supported by supplementary methods such as literature review, expert consultation, and empirical data collection. The chapter is structured as follows: First, the literature search process is described to illustrate the foundation of existing knowledge. Then, the LCA methodology is presented, including its phases, strengths and limitations. Finally, the chapter details the data collection process, including observations, expert inputs, and the use of tools such as SupplyAID and EXIOBASE to support robust modelling.

6.1 Literature Search

The purpose of a literature review is to provide an overview of the sources used in research on a specific topic (Labaree, 2025). In this study, the literature search aims to establish an understanding of the existing knowledge related to quantifying the environmental impacts of a patient pathway. This will provide insight into what other studies have included and excluded and identified as potential pitfalls. This study uses the traditional narrative literature review approach, which involves a focused and delimited literature search based on selection and evaluation of other studies. This approach allows for the exploration of a broader question and the development of new hypotheses that can contribute to the exploration of the research question (AU Libery, 2025; Baumeister and Leary, 1997).

The literature search is in this study structured into eight blocks, each representing a stage in the typical patient pathway for lumbar disc herniation surgery, see Figure 2.1. Table 6.1 provides an overview of these blocks and their specific search criteria.

Each block follows a set of search criteria categorised into three main aspects; environmental impact, healthcare context, and block-specific terms. The environmental and healthcare related criteria remain the same across all blocks. Environmental impacts is included using the following search criteria: *Life Cycle Assessment OR LCA OR Carbon Footprint OR Environmental Impact OR Environmental Assessment*, and the healthcare is included by the search criteria: *Hospital OR Healthcare Sector*, except for scans, as terms such as medical imaging and radiology are used to make the search more specific. Lastly, block-specific terms further refine the search by using key elements of a patient pathway stage. Additionally, the 'Admission' block applies exclusion criteria to filter out studies related to air pollution dust, etc., ensuring a focus on hospital stays and inpatient care.

To maintain relevance with this study, only articles from environmental publishers within the time frame 2000 to 2025 are included. Scopus, SpringerLink, and Web of Science Core Collection are selected as search databases for their individual strengths, where the combination of their strengths enhances the literature review (Aalborg University Library,

Table 6.1. Search blocks and search criteria used in the literature search. Each block represent a stage in the patient pathway and includes specific key terms to use in the database search (own table).

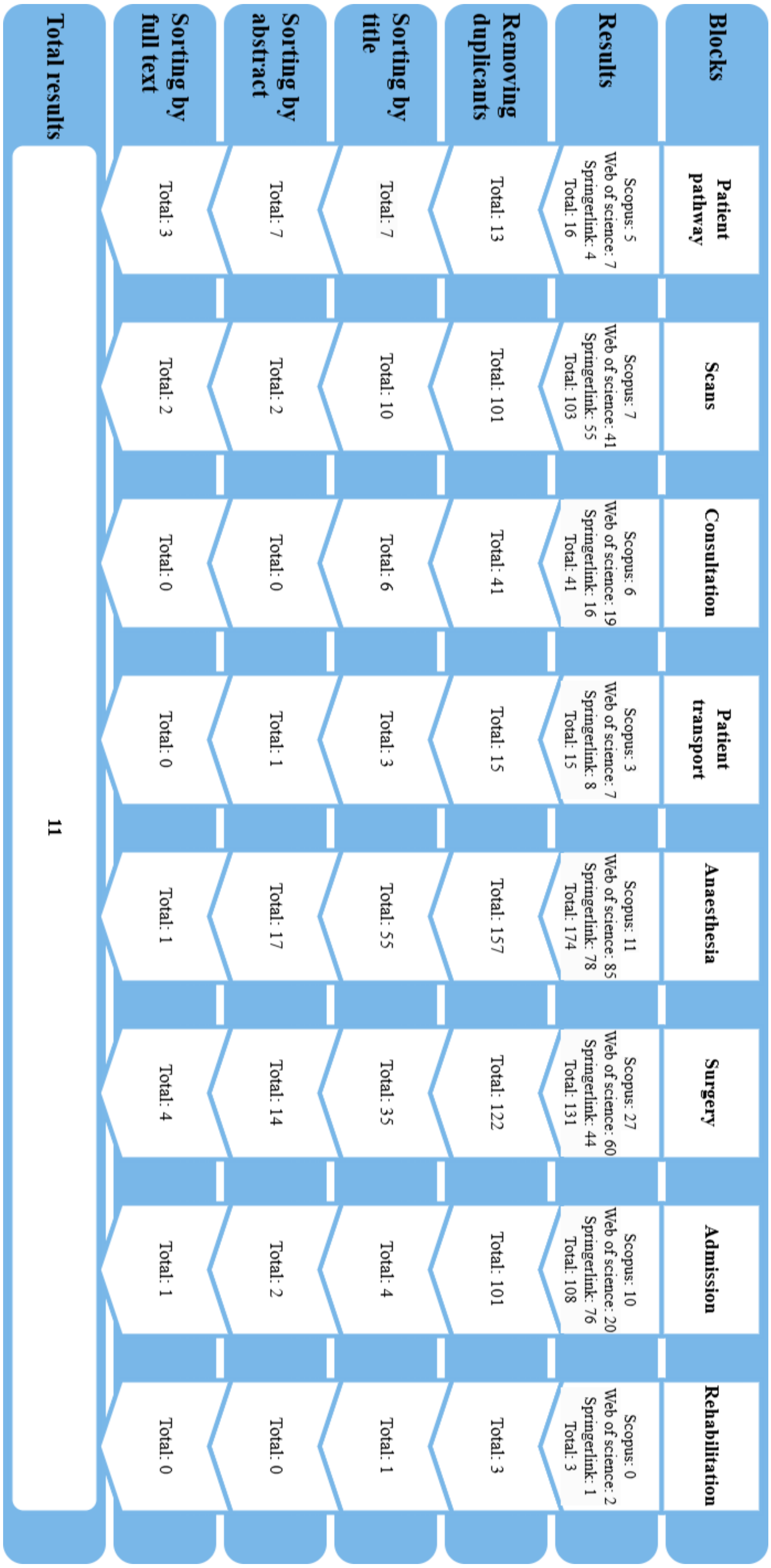
Search Block	Search Criteria
Patient pathway	Patient Pathway OR Healthcare Pathway OR Care Pathway
Scans	Magnetic Resonance Imaging OR MR OR MRI OG MRI Scan OR MRI Examination
Consultation	Consultation OR Doctors Appointment OR Medical Consultation OR Patient Consultation
Patient transport	Patient Transport OR Hospital Transport OR Medical Travel OR Patient Journey
Anaeasthsia	Anaesthesia OR Anaesthesia OR Anaesthetic Gases
Surgery	Surgery OR Surgical Procedures OR Operating Room OR Operation Theatre OR Surgical Suite
Admission	Hospital Admission OR Inpatient care OR Hospital Stay OR Patient Hospitalization OR Admission Corrigation AND NOT Air Pollution OR Air Quality OR Heat-related OR Heat OR Pollution OR Dust OR Sanitation OR Sulphur OR Urban OR Orzone
Rehabilitation	Rehabilitation OR Physiotherapy OR Physical Therapy AND Post surgical OR Postoperative care OR After Surgery

1996, 1832, 1899). Including more search databases ensures wide coverage, as not all published research papers or reports are guaranteed to be available in the same search database. For each block, searches are performed in all three databases. After retrieving the results, a structured screening process is applied to refine the results. The aim is to narrow down the search results to find the most relevant literature narrowed down to a total of articles that are manageable and can be read. First, duplicates within each block are removed as the same article might appear in more than one database. The titles are then reviewed, and articles that are not related to environmental impact and health care or the specific block category are then removed. The abstracts of the remaining articles are then reviewed, where those that do not focus on LCA or other non-relevant study types are removed. Finally, a full-text review of the remaining articles to remove any articles that do not align with the purpose of the literature search, for more detail see the excel sheet in Appendix B. A visual illustration of the screening process can be seen in Figure 6.1.

The search yielded a total of 11 articles. No relevant articles were found for "patient transport", "consultation", or "rehabilitation". However, during the block search for "admission", an article relevant to both "patient transport" and "consultation" was identified. This article was not found in the block search for "patient transport" and "consultation" due to the choice of terminology and narrow search criteria. This article will be included in the results, but not illustrated in Figure 6.1. An overview of all 12 articles is provided in the Appendix B. The results of the literature search will be reviewed in Chapter 7.

6.2 Life Cycle Assessment

LCA aims to assess the environmental impacts of products (including services) throughout its life cycle from raw material extraction to disposal (International Standard, 2006). LCA provides a foundation for decision making when a choice is given or an assessment of alternatives is necessary. In the context of healthcare, this could e.g. be the shift from single use equipment to reusable equipment. This section will be based on the International

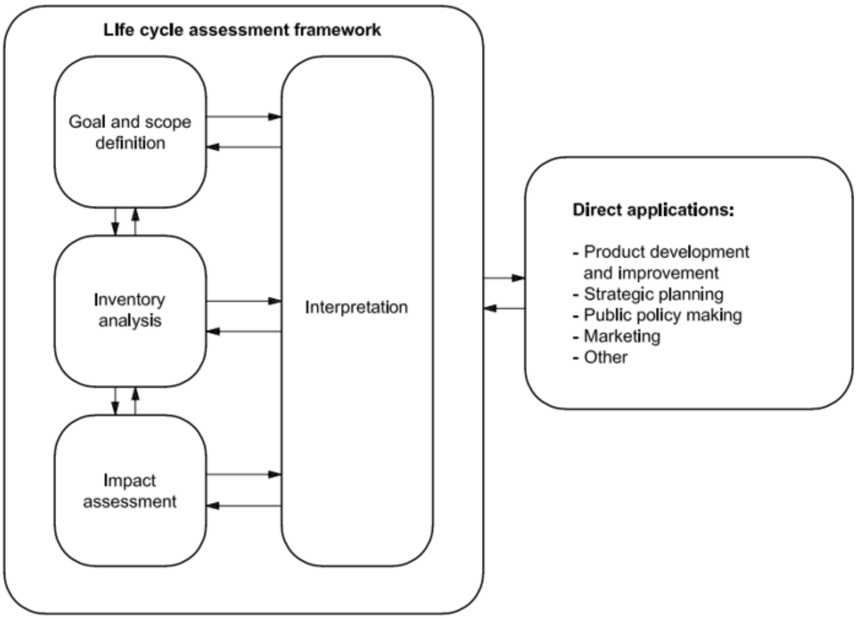


Figur 6.1. Overview of literature search results (own figure).

Organisation for Standardisation's framework on LCA.

6.2.1 Phases of LCA

The ISO framework on LCA provides a set of requirements and recommendations to ensure transparency across different LCA studies and possible comparison for equivalent LCA studies (International Standard, 2006). According to ISO 14044, there are four phases of an LCA study, see Figure 6.2.



Figur 6.2. The four phases of LCA (International Standard, 2006).

It is important to notice that the phases of LCA are illustrated in the figure as an iterative process as the LCA practitioner will need to go back and forth in the order to redefine and adjust some of the definitions, processes, inclusions or exclusions, etc., throughout the study (International Standard, 2006).

Goal & Scope

The first phase of the LCA study states the intention of the study (International Standard, 2006). The scope, system boundary, including foreground system and background system, and level of detail required for the study depends on the goal of the study which is defined through the functional unit of the LCA. According to the ISO standard, the goal and scope of an LCA study must be clearly defined. However, as LCA is an iterative process, the LCA practitioner might need to redefine this throughout the study to ensure consistency (International Standard, 2006).

When defining the goal of the study, the LCA practitioner must explicitly state the intended application, background, audience, and whether the study can be used for comparative studies. The scope of the study adds specific definitions and details for the LCA study, such as the product system, the functional unit, the system boundary, allocation procedures, impact assessment methodology, interpretation approach, data requirements, assumptions, limitations, and chosen reporting format. Additionally, the

LCA study must consider data quality criteria, value choices, and critical review types (International Standard, 2006).

The functional unit of the LCA study and product system must be defined in accordance with one another and must provide a clear reference for the normalisation of the inputs and outputs within the system. As these requirements are fulfilled, the LCA practitioner is able to ensure reliable comparison between systems with the same function (International Standard, 2006).

The system boundary determines what processes to include in the LCA study. The system boundary must be consistent throughout the study. When defining the system boundary, the choices of included and excluded processes and the detail of the included processes shall be explained and justified according to sense-making of the study. The system boundary can beneficially be illustrated through a process flow diagram to show the full system and the processes' interrelations. The ISO standard further sets requirements for the data quality, including its time-related coverage, precision, completeness, reproducibility, sources, uncertainty, etc. (International Standard, 2006).

As this is a comparative study of two surgical procedures treating the same condition, the defined goal and scope must be uniform and comparable. This means that the two assessments should be based on the same functional unit and considerations regarding the defined system boundary.

Life Cycle Inventory Analysis

The LCI includes the data and calculations that are necessary to collect to meet the defined goal of the study. This can be done by gathering primary data that can be obtained by weighing a product, knowing e.g. where it is produced, used, and disposed of. It can also be done by collecting secondary data from the producer, literature, or LCA databases. Usually, the primary and secondary data are combined to fully cover the defined scope of the study. In the LCI, the different unit processes are described and illustrated (International Standard, 2006).

Life Cycle Impact Assessment

The LCIA provides additional information regarding the environmental significance of a product's life cycle. In this step, the LCA practitioner chooses impact categories and characterisation model. In the LCIA phase, the LCA practitioner can also conduct a sensitivity analysis to determine how robust the LCA study is towards possible changes in the process data (International Standard, 2006).

Interpretation

The interpretation is the last phase of the LCA but is also done throughout the other steps as a feedback loop that checks each phase before moving to the next. The interpretation provides a summarised basis for the conclusion of the LCA, including potential issues regarding completeness, sensitivity, consistency, the study's limitations, and recommendations for further study (International Standard, 2006). The interpretation phase can be useful for recommendations of improvements and changes to reduce environmental impacts (Matthews et al., 2014).

6.2.2 Strengths & Limitations of LCA

LCA is one method among several other environmental impact assessment methods. It provides a systematic approach to quantify environmental impacts associated with the life cycle of a product or service. The life cycle perspective is one of LCA's main strengths, as it can be an advantageous approach to avoid burden shifting by identifying environmental trade-offs across stages that might otherwise be overlooked.

Another strength lies in LCA's standardised methodology. It is guided by an internationally recognised framework by the ISO standards 14040 and 14044 (International Standard, 2006). This standard promotes transparency, reproducibility, and comparability across LCA studies. This makes LCA a valuable tool for decision makers aiming to reduce environmental impacts in product design, supply chains, or political contexts.

However, LCA is not always the most suitable method in every context, as it, like other environmental pact assessment methods, has its limitations. A key limitation is that LCA primarily focuses on environmental aspects and often fails to adequately address the social and economic dimensions of sustainability, which are also crucial in decision making for sustainable initiatives. Moreover, the reliability of LCA results is highly dependent on the quality of data and the methodological choices made by the practitioner. Variations in system boundaries, functional units, and assumptions can significantly influence the results and their interpretation. Consequently, LCA inherently involves a degree of subjectivity that is difficult to eliminate.

Additionally, LCA can be time and resource intensive, particularly when comprehensive data collection is required or when analysing complex systems such as the healthcare sector, where indirect effects and shared services are challenging to isolate.

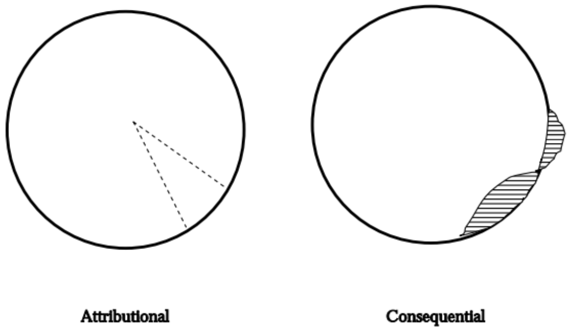
Despite these challenges, LCA remains a valuable tool for identifying environmental impacts and supporting informed decision making toward more sustainable initiatives.

6.2.3 Methodological Approaches of LCA

To better understand and apply LCA, it is important to distinguish between different methodological approaches. These distinctions influence the goal and scope of the study, the data required, and how the results are interpreted. The methods that are distinguishing between are ALCA and CLCA, and process-based, IO-based, and hybrid LCA.

Attributional and Consequential LCA

Attributional LCA (ALCA) and consequential LCA (CLCA) differ in how they represent product systems and allocate environmental burdens. ALCA describes the current environmental impacts of a product system by directly linking the current environmental impacts of a product system by directly linking inputs and outputs to a functional unit. It allocates a portion of existing environmental exchanges to the product, providing a snapshot of its share of global burdens (Sonnemann et al., 2011; Weidema, 2003). In contrast, CLCA models the potential environmental consequences of a change in the demand to fulfil the functional unit. It includes all activities expected to be affected by a change and aims to capture how environmental exchanges would change if a product or service were added, replaced, or removed. An illustration of ALCA and CLCA can be seen in Figure 6.3. This makes CLCA useful for assessing the impact of decisions, such as switching from one product or technology to another (Sonnemann et al., 2011; Weidema, 2003).



Figur 6.3. Difference between ALCA and CLCA. The circles represent the total global exchanges. In the left circle, ALCA seeks to cut out the piece with dotted line that belongs to a specific human activity. In the right circle, CLCA seeks to capture the change in environmental exchanges that occurs as a consequence of adding, replacing or removing a specific activity (Weidema, 2003).

In this study, the CLCA method is used, as the aim is to assess the environmental impact and consequences of changing from one surgical procedure to another.

EXIOBASE

This study uses EXIOBASE as the main background database for conducting LCA. EXIOBASE is a detailed global database developed for environmental and economic modelling. It was originally designed to support environmental footprint analysis and has since become one of the most used tools in environmentally extended IO analysis. IO data utilises a top-down approach and links economic data to sector-level emissions, making it beneficial for complex systems, where product-specific data is not available. The version used in this study, EXIOBASE version 3, provides comprehensive data structured to link economic activity with environmental impacts in a consistent, multi-regional background database.

EXIOBASE combines national supply-use and IO tables with environmental extensions. Therefore, the database does not only show which industries produce goods and services, but also how these activities are connected to emissions, energy consumption, resource extraction, and waste generation. EXIOBASE is based on the economic supply-use table to begin with and then extended with the environmental inputs and outputs where physical data is available and more precise. This makes the data model more convenient to use for LCA practitioners, as some categories, e.g. power or raw materials, are more likely to be given in physical units such as kWh or kg. EXIOBASE version 3 covers 44 countries, five rest-of-world-regions, 200 product types, and 163 industries. This level of detail enables both national and international environmental assessments and makes the database particularly suitable for modelling complex systems with global supply chains.

The hybrid units in EXIOBASE are particularly beneficial in LCA studies such as this, as it allows for combined analysis of physical and monetary flows. This makes it possible to capture environmental impacts when physical data is lacking, and therefore can be covered in monetary units. It should, however, be noted that monetary units can fail to correctly estimate the actual environmental impact of an activity.

Hybrid Data

This study includes data collection on both specific products, but also more general procurement data. Therefore, EXIOBASE is beneficial in evaluating both the physical and monetary processes. However, when analysing specific products and processes, EXIOBASE lacks due to its highly aggregated IO-processes. Process data distinguishes from IO data, as it is based on a bottom-up approach and models individual processes using physical units. While this provides high precision and transparency, it is often limited by system boundary cut-offs and data gaps, especially when assessing broad or complex systems like healthcare services. This study therefore expands its background data foundation by including hybrid processes, combining the strengths of IO data and process data.

The hybrid processes used in this study are provided by the Central Denmark Region. On demand from the Central Denmark Region and the Danish Regions the LCA consultancy company, *2.-0 LCA* has developed hybrid processes. The Central Denmark Region originally started this project with the goal of determining the environmental footprint on products. Therefore, they needed more specific processes for material types than the processes provided by EXIOBASE, e.g. "_59 Plastics, basic". The Central Region Denmark needed to disaggregated the material processes in order to make more realistic environmental footprint results on products.

The hybrid processes are based on an improvement of the material library data foundation, where the IO processes from EXIOBASE have been disaggregated into more specific material categories with process data from Ecoinvent. Ecoinvent has data on more specific products due to its process data. There are limitations in the disaggregation of EXIOBASE and expansion with process data from Ecoinvent, as assumptions have been made where some specific material types are not available or the geographical coverage of Ecoinvent has been limited. The report on how the hybrid processes have been developed underlines the importance in acknowledging that there are improvement opportunities to the new hybrid model, based on the lack of information on geographies and Ecoinvent's inconvenience in confidentiality due to its subscription requirements (Eliassen and Varandas, 2024)(Appendix K).

The hybrid data are integrated into the this LCA study to improve the granularity and accuracy of the results. The aim is to capture the environmental impacts of both surgical procedures in a way that includes detail and systematic completion.

Stepwise

To assess the environmental impacts of the patient pathways of the two procedures, this study uses the Stepwise method implemented in SimaPro. Stepwise is a Life Cycle Impact Assessment (LCIA) method, which includes a broad range of impact categories and allows for results to be expressed both in physical and monetary units. For this study, only the impact category *global warming, fossil* is used. The Stepwise method is selected primarily because it aligns well with hybrid LCA models that draw on monetarised IO databases as EXIOBASE. Stepwise includes monetarised impact categories, enabling consistency when combining process-based data with economic background data (Ministry of Environment and Food of Denmark, 2016). This compatibility improves the coherence of results across both foreground and background data in the hybrid model.

The impact category for global warming in stepwise relies on the acknowledged method for characterisation in accordance with the Intergovernmental Panel on Climate Change's (IPCC) global warming potential (GWP100) (Ministry of Environment and Food of Denmark, 2016). Therefore, Stepwise is an impact assessment method that is aligned with the international standard and can be used directly for comparison with other studies based on the same characterisation factor for Global Warming.

6.2.4 Data Collection

The data collection for this study combines observation, informal conversations with healthcare professionals, and analysis of medical products used in the two procedures. The process follows a pragmatic approach without following a strict methodological structure, focusing on gathering relevant information about the two procedures and their use of materials.

Observation:
Observations include one open procedure performed at AUH and two endoscopic procedures performed at AaUH. Each procedure is observed from start to end, with particular attention to the number of people present in the operating room, the use of medico-technical instruments, and the application of single use equipment and reusable instruments. Additional observations are conducted in the recovery room, also called the postoperative care unit, and the central sterilisation unit, to gain a better understanding of the workflow before and after surgery.

Conversations with Experts:
Informal conversations are conducted with healthcare professionals from various departments, including inventory and supply management, operating room and anaesthesia nurses, surgeons, the director of the technical department of the medico-technical instruments, the chief of the brain and spine ward at both AUH and AaUH, and a hospital porter. These conversations contribute to practical perspectives and expert validation of the collected data. The purpose of these informal conversations is to gain a deeper understanding of daily workflows, logistical challenges, and the use of medical equipment in the real world. They also provided insight into the broader organisational sustainability considerations that influence product usage and waste management. By engaging with experts who have hands-on experience, it was possible to validate assumptions, clarify observed patterns, and uncover barriers.

Collection and Analysis of Products:
During surgical procedures, single use equipment are collected in collaboration with the department of inventory and supply management. Both single use equipment and reusable instruments are weighted and material composition is identified for those where it was possible. For single use equipment, a plastic scanner is used to determine the specific plastic type, which supports a more accurate modelling of material types used for the LCA.

To further supports this efforts and improve oversight of medical supply usage, the

Central Denmark Region, in collaboration with the supply and inventory manager, Ørum, developed the software tool SupplyAID in May 2024. SupplyAID is part of a larger transformation of material and supply logistics in operating rooms, shifting these tasks from clinical staff to logistics personnel (Appendix L). The purpose of SupplyAID is to optimise the stock and usage of medical equipment and improve sustainability by minimising waste by ensuring proper waste sorting and ensuring products are used within their expiration date. SupplyAID provides a detailed overview of the consumption of single use equipment for specific surgical procedures. It is integrated with the Central Denmark Region internal inventory catalogue, *VareDB*, which contains all medical equipment under purchase agreement. This integration ensures that all medical equipment under the purchase agreement is available and up-to-date in the system(Digitalisering og It, Region Midtjylland, 2024) (Appendix L).

In the context of open surgery, SupplyAID has been actively used to collect data on the single use medical equipment used for the open procedure. This makes it possible to track exactly which equipment is used, how often it is used, and for which specific patient. This has not been possible for the endoscopic procedure, as AaUH does not have access to a similar inventory management tool.

The AUH procurement department has data available for the total cost for the different departments at AUH, which is found in the internal Business Intelligent (BI) portal. This includes data from all the wards within the Department of Brain and Spine Surgery, including offices, operating rooms, recovery ward, and ward. This data is used as foundational data to ensure that all costs for the department are included in the LCA calculation for a patient pathway. The categories are given in United Nations Standards Products And Services Code (UNSPSC), which is a global classification system of products and services. The UNSPSC code system is used to classify supplier's products and services, and by registration in the United Nations Global Marketplace (UNGM) suppliers are required to provide information about their activities by following the UNSPSC code classification accordingly (United Nations Global Marketplace, 2024). The UNSPSC codes are translated into EXIOBASE categories, making it possible to convert procurement activities into EXIOBASE format and assess the associated environmental impacts. To enable this translation, Table D1 in Appendix D provides a mapping between the UNSPSC codes and their corresponding EXIOBASE categories, along with the EXIOBASE number for the corresponding EXIOBASE process, which is also used in the LCI tables in Section 8.2.

6.3 Utilisation of AI

In this study, artificial intelligence (AI) has been used as a supportive tool for data processing, modelling decisions, and communication. Specifically, AI has assisted in synthesising large amounts of data related to for example the literature search and narrowing down the relevant articles for the study. By leveraging the services of AI, this study has been able to streamline complex analytical tasks, such as converting findings into summarisations on the current knowledge on patient pathways and the environmental impacts related to surgical treatments. Additionally, AI has been utilised to translate appendix materials, including notes from meetings, emails, and data collection documents, into English.

More specifically, ChatGPT has been used for inspiration and sparring, while NotebookLM has supported the organisation and interpretation of literature, thereby supported the literature review (OpenAI, 2022; NotebookLM, 2025). Copilot has contributed to refining and streamlining the language and structure of the report. Since the report includes material that is considered confidential, Copilot was chosen as it operates within Microsoft 365's closed system. This is important as it ensures that sensitive information is not shared externally (Microsoft 365, 2025). These tools have contributed to a more structured workflow and enabled the study group to maintain a clear overview throughout the process.

Furthermore, AI has been used to extract key insights from technical reports, accelerating the writing process and allowed the researchers to focus more on critical reflection and interpretation of results. While AI has provided valuable inputs, all final modelling decisions, interpretations, and conclusions have been made by the researchers. AI has therefore served as a collaborative tool that has helped improve the efficiency and transparency of the overall LCA study.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Literature Review 7

This literature review aims to establish a comprehensive understanding of how the environmental impact of a patient pathway is quantified, highlighting key considerations and challenges. 12 relevant articles are analysed, providing insight into methodologies and findings related to environmental assessment in healthcare. An overview of these articles can be seen in Appendix B. Many of the articles emphasise the importance of quantifying the environmental impacts in the healthcare sector to support informed decision making and to reduce the sector's environmental impact .

7.1 Environmental Quantification in the Healthcare sector

The healthcare sector has been increasingly recognised as a significant contributor to environmental challenges, primary through high levels of waste generations, intensive use of resources, leading to green house gas emissions. The articles found in the literature search point out that there is a growing need for sustainable transformation within healthcare, in order to lower the environmental impact it is currently contributing to (Bischofberger et al., 2023; Sack et al., 2024; Silva de Souza Lima Cano et al., 2025; Sathe et al., 2024; Savio et al., 2024; McAlister et al., 2022).

A common theme across these articles is the focus on quantification as a critical tool for understanding and assessing these environmental challenges. By systematically measuring the environmental impact of healthcare activities, it becomes possible to identify the most resource intensive and environmentally challenging areas, whether they are specific departments, products, or surgical procedures. This type of data insight is essential for targeting efforts for improvements. Among these articles most frequently identified though these analyses are operating rooms, which are considered to stand out due to their high consumption of single use equipment, energy intensive practice, and strict sterilisation requirements. This makes the operating room one of the focus areas for environmental improvement initiatives (Silva de Souza Lima Cano et al., 2025; Thiel et al., 2015; Savio et al., 2024; Bischofberger et al., 2023; Zhang et al., 2022; Prasad et al., 2022; Sack et al., 2024; McAlister et al., 2022; Sathe et al., 2024; Jiménez-Lacarra et al., 2024).

Quantified data is important, as it can be used for decision making about procurement, choice of treatment methods, selection of medical products, and streamline procedures among surgeons. This includes strategies to reduce the environmental footprint of the healthcare sector, such as choosing treatments and equipment with a lower environmental impact, optimising energy consumption, and reducing waste. Measurable and quantified data can also raise awareness of the environmental footprint of the healthcare sector among healthcare professionals, management, and patients, promoting participation in sustainability initiatives. This awareness can guide procurement decisions towards more environmentally friendly products and practices, including reusable instruments and equipment that can be recycled (Gasciauskaite et al., 2024; Prasad et al., 2022; Thiel et al., 2015; Sathe et al., 2024; McAlister et al., 2022; Sack et al., 2024; Savio et al., 2024; Bischofberger et al., 2023; Silva de Souza Lima Cano et al., 2025).

7.1.1 Quantification Methods

The primary method used to assess the environmental impact in healthcare is LCA. Since the study focuses on LCA as the main quantification method, most of the articles included in this review employ LCA, either as a process-based approach, an economic IO-based approach, or the hybrid approach (Thiel et al., 2015; Prasad et al., 2022; Esmaeili et al., 2018; Silva de Souza Lima Cano et al., 2025; McAlister et al., 2022; Zhang et al., 2022; Prasad et al., 2022; Sack et al., 2024). In addition, some articles also incorporate waste audits to assess hospital waste generation (Thiel et al., 2015; Prasad et al., 2022; Silva de Souza Lima Cano et al., 2025; Savio et al., 2024).

7.1.2 Environmental Impact of Different Patient Pathway Stages

Full Patient Pathway:
Three articles assess the environmental impact of an entire patient pathways. Bischofberger et al. (2023) evaluates a colorectal surgery pathway, finding an average footprint of 1,303 kg of CO_2-eq per patient, the study includes all stages related to colorectal surgery, but excludes emissions from the supply chain and patient transport. The most significant contributors were the use of energy and the use of single use medical equipment in the operating room (Bischofberger et al., 2023). Zhang et al. (2022) examines the carbon footprint of acute decompensated heat failure (ADHF), from pre admission to discharge. The article finds an average impact of 72,652 kg CO_2-eq per patient, with hospital admission contributing the most emissions due to high energy consumption and resource use (Zhang et al., 2022). The last article, by Sack et al. (2024) compares two patient pathways for coronary stenting and coronary artery. It includes all factors from admission to discharge, including hospital management, supply of medical equipment, and energy use. Coronary stenting has an environmental impact of 2.4 tonnes CO_2-eq per patient, whereas coronary artery results in 11.5 tonnes CO_2-eq per patient, primarily due to increased resource consumption and the duration of surgical time (Sack et al., 2024).

Consultations and Patient Transport:
An article by Jiménez-Lacarra et al. (2024), investigates how shifting consultations from hospitals to primary healthcare centres can reduce patient transportation, and consequently, CO_2-eq emission. The study establishes a linear relationship between patient transport and CO_2-eq emissions, which means that reducing transport directly leads to lower CO_2-eq emissions. Although the article does not focus exclusive on transport, it highlights it as a contributor to CO_2-eq associated with hospital visits. Two scenarios were analysed: one using traditional vehicles and the other using electrical vehicles. The results show that the use of electric vehicles combined with the reduction of unnecessary transport could, on average, reduce the environmental impact by 26% (Jiménez-Lacarra et al., 2024).

Scans:
An article by McAlister et al. (2022) a comprehensive LCA study was conducted of five

common imaging models in Australia; Magnetic Resonance Imaging (MRI), Computorised Temography (CT), Chest X-ray (CXR), Mobile Chest X-ray (MCXR), and Ultrasound (US). The study included direct electricity use of the scanners, its associated standby power consumption, the consumables, and the generated waste from this. The overall results showed the following environmental impact results of the different scan types: 1.1 kg CO_2-eq for MRI and CT, 0.6 kg CO_2-eq for CXR, and 0.1 kg CO_2-eq for MCXR. Overall the study concluded that the significant impact came from standby power consumption (McAlister et al., 2022). This highlights a potential for energy savings throughout the surgery, where the device is on standby-mode. Another article by Esmaeili et al. (2018) provides a detailed LCI and carbon footprint analysis for MRI services based on ISO 14040 and 14044 standards. The study includes the use of material and energy for MRI scans and estimates an emissions of 22.4 kg CO_2-eq per scan (Esmaeili et al., 2018).

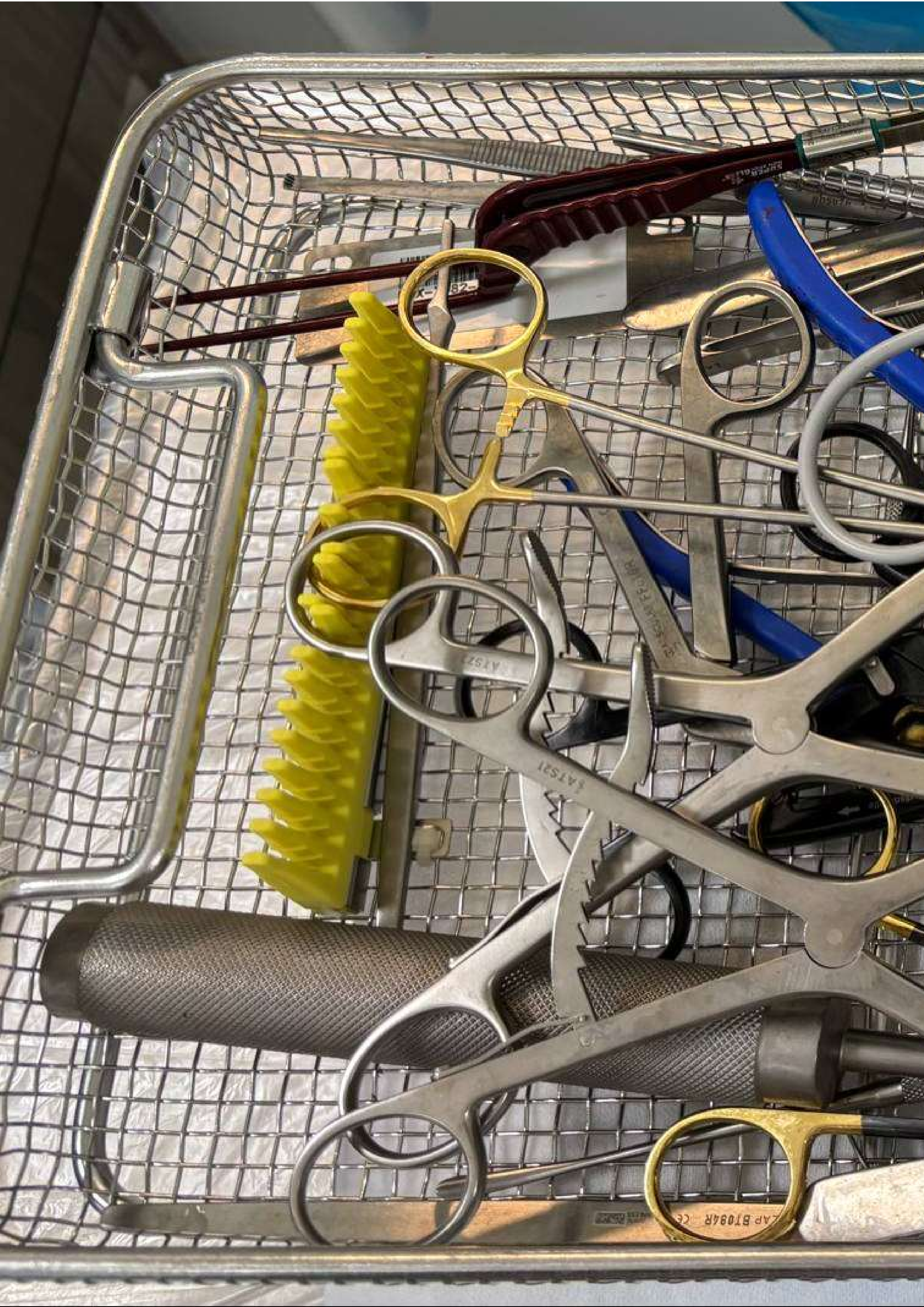
Anaesthesia:
Gasciauskaite et al. (2024), investigates the environmental impact of different anaesthetic gases, including sevofluran, desfluran, and propofol. The article includes emissions from evaporated anaesthetics and the production and disposal of medical equipment. The finding shows that sevoflurane has a GWP100 of 130, which is the most used gas for anaesthesia in the Danish health care sector, while desflurane has a significantly higher GWP100 of 2540. Propofol, administered intravenously, has an estimated environmental impact of 21 g CO_2-eq per g (Gasciauskaite et al., 2024).

Surgery:
Several articles assess the environmental impact of surgery. Thiel et al. (2015), evaluates four types of hysterectomy: abdominal, vaginal, laparoscopic, and robotic-assisted. The study includes everything from the production to disposal of medical instruments, heating, ventilation, and air conditioning (HVAC), energy consumption, anaesthesia, and waste management. The robotic-assisted procedure had the highest emissions due to single use equipment, while the vaginal procedure had the lowest (Thiel et al., 2015). Another article by Silva de Souza Lima Cano et al. (2025), examines the environmental impact of anterior cruciate ligament reconstruction (ACLR). The assessment includes energy use, production and disposal of single use medical equipment, and HVAC-system. The total environmental impact of ACLR is estimated to be 47 kg CO_2-eq per procedure, with the production of medical equipment being the biggest contributor (Silva de Souza Lima Cano et al., 2025). Sathe et al. (2024), explores variability in surgical instruments use, emphasising that the lack of standardisation affects CO_2 emissions. The article does not quantify emissions, but highlights how surgeon preferences influence environmental impact (Sathe et al., 2024). Savio et al. (2024), reviews existing LCA studies in operating rooms and proposes a framework to carry out comprehensive LCAs. The framework includes raw materials, production, transportation, and end-of-life for all stages of surgical phases: presurgery, surgery, and postsurgery. However, it does not provide specific CO_2-eq (Savio et al., 2024).

Admission:
A study by Prasad et al. (2022), assesses the environmental impact of standard and intensive hospital admission in a large American hospital. The assessment includes factors such as procurement, energy consumption, use of medical equipment, food supply, personnel, and transport. Emissions for standard hospital admission result

in approximately 45 kg CO_2- eq per bed stay, whereas intensive admission results in approximately 138 kg CO_2- eq per bed stay. The main contributors to emissions are procurement and energy consumption (Prasad et al., 2022).

The reviewed literature highlights critical challenges in assessing and mitigating the environmental impact of the healthcare sector. A major challenge is the lack of detailed emission data for medical products, pharmaceuticals, and procedural variations, which limits the precise assessment. Additionally, Savio et al. (2024) emphasises the need for a standardised approach to conduct LCA in the healthcare sector to enhance comparability across studies. Another identified challenge is variability in surgical instrument use, as highlighted by Sathe et al. (2024), which demonstrates how a lack of standardisation leads to inconsistency. The literature search emphasises an overall need for further exploration of the environmental impact activities in healthcare, as it is currently difficult to estimate. This justifies the need for a study that quantifies the environmental impacts in connection with surgical procedures, which this study aims to contribute to.



First Analysis – LCA of Procedures 8

This chapter will address the first sub-question:

What is the environmental impact of open procedure and endoscopic procedure?

The environmental impacts of the two surgical procedures for treating lumbar disc herniation; open procedure and endoscopic procedure, will be quantified using LCA. This constitutes a comparative LCA study of the two types of surgical procedures.

Before data collection, it was intended to divide the collected data into stages of a patient pathway in relation to lumbar disc herniation surgery. A division like this could have been presented as a chronological order of; diagnostics, patient travel, consultation, presurgery, surgery, postsurgery, discharge, self-care, and rehabilitation. However, after a more comprehensive data collection, it was found that a division based on this was not feasible for this study. As the foundation of the LCA is based on the economic data obtained through BI portal, of the Department of Brain and Spine Surgery, this data is very aggregated and therefore includes all procurement activities for the entire department. This therefore also entails inclusions of products or equipment that is used outside of the operating room, therefore as part of the stages for e.g. consultation, pre surgery or post surgery, and discharge, and is therefore already accounted for in the economic data. Instead of dividing the LCAs into stages, it has been decided to divide them into categories that have been natural for the process of conducting the LCAs and therefore correlate with the LCI tables. The categories to be assessed for this analysis are the following;

- Patient travel
- Procedure kit
- Anaesthesia equipment
- Open surgical procedure
  - Single use equipment
  - Reusable instruments
  - Medico-technical instruments
  - Pathway
- Endoscopic surgical procedure
  - Single use equipment

- Reusable instruments
- Medico-technical instruments
- Pathway

The case of open procedure is built on knowledge from AUH (Appendix A), where the case of endoscopic procedure is built on both knowledge from AUH and AaUH (Appendix A and C). The comparative LCA study will provide a starting point in conducting LCA of the surgical procedures, each calculated with an estimate of three surgeries per day.

8.1 Goal & Scope

The goal of this study is to quantify and compare the environmental impacts of two surgical procedures used to treat lumbar disc herniation; open procedure and endoscopic procedure. The impacts will be assessed in CO_2-eq, in terms of GHG emissions measured using the IPCC GWP100 (Green House Gas Protocol, 2024), following the principles and methodology described in the ISO 14040 and ISO 14044 standards on LCA. The results aim to inform decision making in the Department of Brain and Spine Surgery at AUH, which is currently evaluating a potential transition from open procedure to endoscopic procedure. The LCA findings can be further communicated to other hospitals abroad to inform and transform sustainable healthcare beyond national borders.

8.1.1 Functional Unit

The LCA uses the following functional unit:

"The surgical treatment of an average patient with lumbar disc herniation beginning after diagnosis by the patient's own doctor and ending after the patient is discharged from hospital."

This definition enables a meaningful comparison of the two procedures, as both aim to deliver the same clinical outcome. It should be noted that the functional unit does not consider cases where patients may require additional or repeated surgical interventions in the future or have had similar treatment performed previously. This will not be taken into account in the LCA study.

The functional unit provides a consistent basis for comparing the two surgical procedures, both of which are effective in treating lumbar disc herniation and meet the clinical criteria for recovery from lumbar disc herniation. Although functionally equivalent, long-term results can vary significantly due to individual patient factors such as rehabilitation after surgery, physical conditions, psychosocial environment, and heriditary predispositions. As highlighted by Bjarkam, these elements can influence recovery and the likelihood of requiring further treatment, including a second or third surgery (Appendix C).

In addition to clinical considerations, environmental impacts can differ between procedures. These variations can result from differences in surgical duration, the type and quantity of medical equipment used, and the occurrence of complications. In particular, such factors are often influenced by surgeon preferences and patient-specific characteristics, including age and general health status (Sathe et al., 2024).

8.1.2 Product System & System Boundary

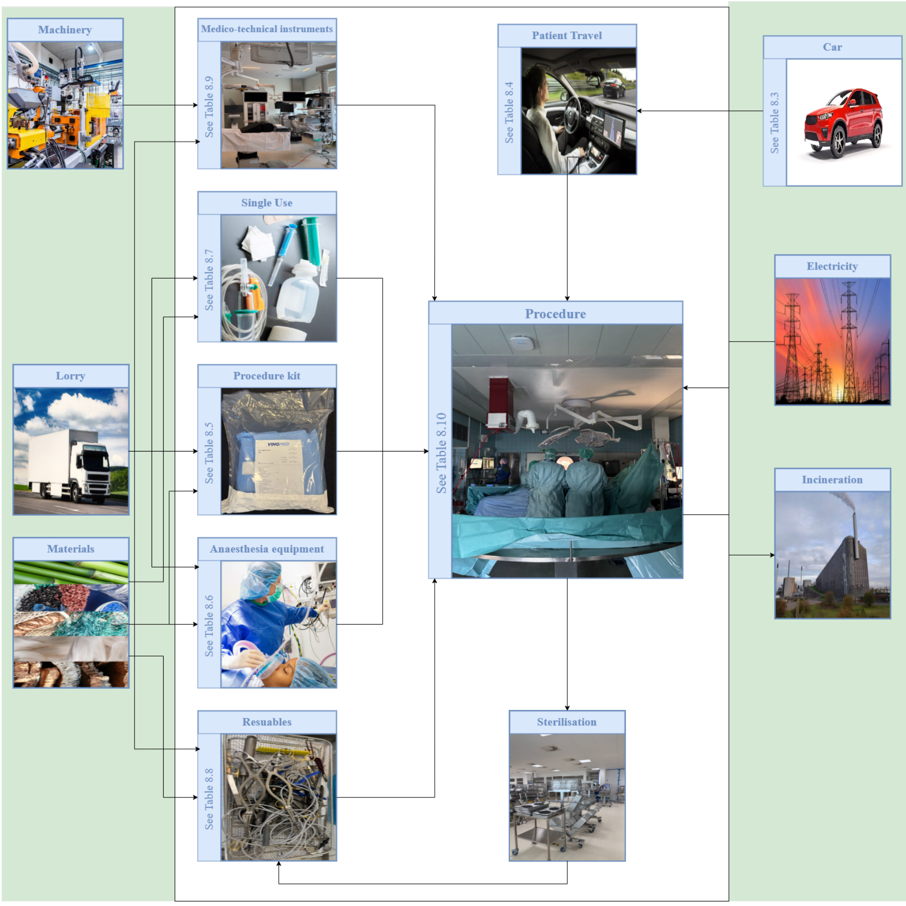
For this LCA, it has been crucial to define a clear system boundary, as the product system of a patient pathway can include numerous activities depending on the specific patient. The system boundary is ultimately defined depending on the intended level of detail and completeness of the LCA study. First, it has been decided to focus on the environmental impacts from the hospital's point of view. This means, that only activities and consumables directly managed by the hospital are included in the assessment. For example, pharmaceutical drugs administered to the patient during admission are considered. In contrast, pharmaceuticals purchased by the patient after discharge are excluded, since they fall outside the hospital's control and vary between patients. Similarly, postoperative rehabilitation in the form of physiotherapy provided through municipal services is not included, as it is difficult to consistently determine and quantify.

As this is a comparative LCA study of the open versus endoscopic surgical procedure, the focus has also been to map out where the two procedures are different from each other. It has been anticipated that where activities are different in the two procedures, these are where different environmental impacts will be highlighted, as the same activities will ultimately result in the same environmental impacts. Activities that apply to the patient pathway for both surgical procedures have therefore been a secondary focus or excluded if they required more comprehensive data collection or processing. The choice of excluding these types of activity has compromised the objective of mapping an entire patient pathway in connection with surgical treatment for lumbar disc herniation, but has allowed for a deeper focus and detail for the activities that were different from one another. This focus has given the comparative LCA study the potential to highlight the implications of a potential change in practice and how the two types of procedure perform in terms of each of their environmental impacts. The product system can be seen in Figure 8.1.

The figure illustrates the product flow associated with both of the surgical procedures. As the same categories are involved in both procedures, a shared product system has been established to represent both. The product system is divided into two sections. The white background represents the foreground system, which includes processes and categories specific to the procedures. These are based on primary data and include for example the procedure kit, anaesthesia equipment, reusable instruments, single use equipment, and medico-technical instruments, which all goes into the pathway of the procedure. The green background represents the background system, which includes the processes modelled using background data from EXIOBASE and the hybrid processes devolved for the Danish Regions. Specifically, all material processes in the background system are based on hybrid processes, ensuring regional relevance, whereas background processes including electricity production, machinery transport, and end-of-life treatment, use EXIOBASE processes. For processes in which LCI table have been compiled, a reference to the corresponding table is provided in the figure and will be elaborated in Section 8.2.

The system boundary defines which processes are included in the assessment of the surgical treatment. The LCA follows a cradle-to-grave approach, encompassing all activities from the extraction of raw materials and manufacturing of medical devices and supplies, to their use during surgery and final disposal.

The system boundary is based on the procurement data from the Brain and Spine



Figur 8.1. Product flow illustrating input and outputs to a surgical procedure for disc herniation (own figure).

Department of AUH, which serves as the foundational dataset. Where available, the monetary data have been supplemented or replaced by physical data to improve accuracy and avoid double counting. This approach ensures a comprehensive representation of all relevant activities that contribute to the environmental impact of lumbar disc herniation, for almost all stages of the pathway.

Included in the system boundary is following:

- Procurement for the Brain and Spine Department
- Consultations
- Procedure kit
- Single use equipment
- Reusable instruments
- Drugs and pharmacy
- Transportation of medical equipment and products
- Medico-technical instruments and its energy consumption
- Energy and water use for the entire department of Brain and Spine Surgery
- Post operative recovery
- Textiles and clothing

- Infrastructure (e.g., hospital building and capital goods)
- Sterilisation of reusable instruments including energy, water, and re-packaging
- Patient travel to and from the hospital
- Employee expenses (nurses, surgeons, porters)
- Admission

Excluded in the system boundary is following:

- Patient or relative transportation and visits
- Transport or other activities in connection with employees beside surgery
- Diagnostics at own doctor
- Self-care at home after discharge
- Rehabilitation

These exclusions are made according to ISO 14044, which allows the exclusion of life cycle stages, processes, inputs, or outputs of the life cycle, if they are shown to have an insignificant influence on the overall result and conclusion (International Standard, 2006). In some cases, such as diagnostics performed by the patient's own doctor or self-care at home, reliable and consistent data were not available, making it difficult to model accurately. Other activities, such as employee travel, were excluded as they are assumed to be identical across both procedures and therefore do not influence the outcome determining which procedure has a lower total emission. Rehabilitation represents a more complex case. Although it is likely to differ between the two procedures, it has been excluded due to the lack of data. This means, that a potential difference is not captured in the current analysis. The rationale for the exclusion is, therefore, based on the availability, comparability, and environmental significance of the data.

A key uncertainty in this study arises from the exclusion of post discharge activities, particularly rehabilitation. As highlighted by Oettingen and Bjarkam, endoscopic procedure patients typically experience a shorter recovery period post surgery compared to those who received the open procedure, due to the less invasive nature of the procedure. This difference is not reflected in this LCA, as post discharge stages were excluded from the system boundary (Appendix C). As a results, the potential environmental benefits associated with faster recovery and reduced need for rehabilitation in endoscopic procedures may be under represented. This introduces a limitation in the interpretation of the results, as the LCA does not capture the full extent of difference in patient outcomes.

8.1.3 Data and Modelling Approach

The LCAs are conducted using EXIOBASE, a hybrid IO-based approach. Primary data is collected from AUH's surgical and technical departments regarding use of single use equipment, and energy consumption. Secondary data, including emission factors and production, are sourced from the EXIOBASE database and the EXIOBASE expansion with specific hybrid process for material types.

Due to confidentiality and market competition, the prices on different products and services are kept confidential, as this would otherwise compromise the enabling of the study. To ensure a transparent LCA study regardless of this, several measures have been taken. First, the structure and logic of the calculations are carefully documented, allowing other LCA practitioners or individuals to understand how the results were derived. Secondly, data sources and assumptions are described in detail to ensure that the recipient can evaluate the robustness and relevance of the data. Where possible, anonymised or aggregated monetary data are represented in relative terms. Furthermore, sensitivity analyses have been performed to assess how variations in key parameters affect the results, which adds an additional layer of transparency. By clearly distinguishing between what is based on confidential input and what is publicly accessible, the LCA study enables critical assessment and reproducibility to the possible extent.

As EXIOBASE uses a monetary unit in EUR2011 this has been translated using a currency calculator and adding the inflation value from 2011 to 2024 in order to provide a unit in DKK2024. This has been done to enable the LCA calculation from the DKK2024 unit in the procurement data to EXIOBASE's EUR2011 unit. The inflation of DKK from 2011 to 2024 is established based upon data from Danmarks Statistik (2023). The conversion is calculated as follows:

$$1textEUR2011 = 7.45 \text{ DKK2011} \Rightarrow 1 \text{ DKK2011} = \frac{1}{7.45} = 0.13 \text{ EUR2011}$$

The inflation factor from 2011 to 2024 was 1.24

To express DKK2024 in terms of EUR2011, the inflated value was divided by the 2011 exchange rate:

$$\frac{0.13}{1.24} = 0.11 \text{ EUR2011 per DKK2024}$$

The DKK2024 is afterward applied in SimaPro's unit catalogue enabling an automatic calculation from EUR2011 to DKK2024 between processes in SimaPro.

8.2 Life Cycle Inventory

Data for the LCAs are collected and organised into categories in order to provide structural overview of the total environmental impact. The categorisation allows for evaluation of each category and its relative contribution to the overall impact.

For both the open and endoscopic procedures, the procedure kit, anaesthesia equipment, and patient travel is modelled identically. These categories are therefore treated the same in both the procedures LCI tables, as they do not contribute to the difference between the two procedures. In contrast, differences arise in the data for single use equipment, reusable instruments, medico-technical instruments, and the procedure pathway. while the underlying process remains consistent, the quantity and type op input vary between the two procedures.

To ensure consistency and avoid double counting, physical data have been prioritised where available data. In cases where both physical and monetary data were available, monetary inputs have been adjusted by subtracting the contribution already accounted for through physical inputs.

The following sections present the LCI tables for the open procedure only, where relevant differences compared to the endoscopic procedure are described. A complete set of LCI tables for both the open and endoscopic procedure can be seen in Appendix E.

Transport

In this study, the transportation of equipment from the manufacturing site to AUH is included in the following LCI tables. To provide a more activity based and physically representative account of transport processes, the transport data from EXIOBASE, which originally is expressed in monetary units (MEUR2011), is converted into physical units (tkm). These conversions are applied to 23 geographies, covering all land transport and selected sea transport processes. Table 8.1, provides an overview of the countries, their corresponding country codes, which are used to specify the origin of material and transport processes in the LCI tables in Appendix E, and the types of transport processes e.g. land or sea that are converted using this calculation.

Table 8.1. Overview of geographical areas, codes and the processes that have been converted from monetary to physical units (own table).

Geography		Transport type	
Code	**Country**	**Land**	**Sea**
AU	Austria	X	
CA	Canada	X	X
CNTW	China	X	X
DK	Denmark	X	
ES	Spain	X	
FI	Finland	X	
FR	France	X	
DE	Germany	X	
GB	Great Britain	X	X
IE	Ireland	X	X
IT	Italy	X	
LI	Lithaunia	X	
MX	Mexico	X	X
NL	Netherlands	X	
NO	Norway	X	
PO	Poland	X	
PT	Portugal	X	
WA	Rest of Asia	X	X
WM	Rest of Middle East	X	X
SE	Sweeden	X	
CH	Switzerland	X	
TU	Turkey	X	X
US	United States	X	X

An example of this conversion is shown for Danish land transport process *"122 Other land transport DK"*. The process is first extracted from EXIOBASE, and imported into Excel, where all transport processes not related to land transport are excluded by setting their input values to zero. These excluded values are then subtracted from the total process output to maintain mass balance.

The Danish land transport process requires 290,652.61 tonnes of fuel to deliver 11,852.96 MEUR2011 land transport. To convert this into physical units, the fuel efficiency per tkm of a representative European lorry from Ecoinvent is used. The process *"Transport, freight, lorry 16-32 metric ton, EURO6 RER| transport, freight, lorry 16-32 metric ton, EURO6 | Conseq, U,"* reports a fuel consumption of 0.036646054 kg fuel per tkm.

The conversion is calculated as follows:

Fuel per MEUR2011:

$$\frac{\text{tonnes fuel}}{MEUR2011} \Rightarrow \frac{290,652.6148 \text{ tonnes fuel}}{11,852.96064 MEUR2011} = 0.040780506 \text{ tonnes fuel per MEUR2011}$$

Conversion of kg fuel to tonne fuel:

$$\frac{\text{kg fuel per tkm}}{1,000} \Rightarrow \frac{0.036646054 \text{ kg fuel per tkm}}{1,000} = 0.000036646054 \text{ tonne fuel per tkm}$$

Determine tkm per MEUR2011:

$$\begin{aligned} \text{tonne fuel per MEUR2011} \cdot \text{tonnes fuel per tkm} \Rightarrow \\ 0.040780506\text{tonne fuel per MEUR2011} \cdot 0.000036646054\text{tonnes fuel per tkm} = \\ 0.000001494445\text{tkm per MEUR2011} \end{aligned}$$

Conversion to tkm:

$$\begin{aligned} \text{MEUR2011} \cdot \frac{1}{\text{tkm per MEUR2011}} \Rightarrow \\ 11,852.96064 \text{ MEUR2011} \cdot \frac{1}{0.000001494445 \text{ tkm per MEUR2011}} = \\ 7,931,348,210.8392 \text{ tkm} \end{aligned}$$

The calculated transport in tkm replaces the original monetary input. The same method is applied across all relevant geographies listed in Table 8.1, including sea transport, where an Ecoinvent container ship process is used instead of a lorry. Specific conversion calculations are provided in Appendix E. The resulting physical transport processes are then used in the LCI tables below.

Patient Travel

In this study, a process for patient travel by car is modelled. Since EXIOBASE does not include a specific process for a car driving one km, a new process is modelled. The process is modelled in four steps to ensure that car manufacturing, fuel consumption and direct CO_2 emissions are represented per km.

Only a petrol car is considered in this study as patient travel, as the primary focus of this study is the comparison of the two surgical procedures rather than transport technologies. Moreover, since the transport process is applied to both procedures, the choice of car does not influence the comparative aspect of the results.

Allocation of car manufacturing:
It is assumed that a car has a total lifetime distance of 300,000 km over its service time (Bilbasen Blog, 2024). This total distance is used to allocate the environmental impact of manufacturing across each km driven, and therefore determining the cars impact per km.

$$\frac{1 \text{ car}}{300,000 \text{ km}} = 3.33333E - 06 \text{ car pr km}$$

Fuel Consumption per km:
To calculate the fuel consumption per km, a vehicle's fuel efficiency is found to be 28.4 km per l (Danmarks Statistik, 2023). This value is then converted into l per km by:

$$\frac{1}{28.4} \text{km per litres} = 0.035211 \text{ litres per km}$$

This value is afterward converted into fuel mass. Knowing a petrol density of 0.8 kg per l, the fuel consumption per km in kg is calculated as follows:

$$0.035211 \text{litres per km} \cdot 0.8 \text{ kg per l} = 0.028169 \text{ kg per km}$$

Finally, the CO_2-eq per km are calculated. This is done by multiplying the fuel consumption in kg per km by the energy content of petrol and then the CO_2 emission factor per MJ of petrol:

- Energy content of petrol: 43,8 MJ per kg
- CO_2 emission factor per MJ of petrol: 74 g CO_2 per MJ

The total emissions per km are calculated as follows:

$$0.028169 \text{ kg per km} \cdot 43.8 \text{ MJ per kg} \cdot 74 \text{ g } CO_2 \text{ per MJ} = 91.3 \text{ g } CO_2 \text{ per km}$$

The calculations presented above form the basis for modelling the LCI for one car driving one km, the modelling can be seen in Appendix E. The LCI Table 8.2, summarises the inputs and emissions associated with one km of patient travel, including car usage, petrol consumption, and the related CO_2 emissions.

Table 8.2. LCI table of car (own table).

Flow	**Unit**	**Amount**	**LCI data**
Reference flow			
Car driving	p	1	Reference flow
Inputs			
Car	p	3.33333E-06	29
Petrol	kg	0.03	57
CO_2	g	91.30	Carbon dioxide, fossil

Table 8.2, presents the reference flow for one car driving one km. Table 8.4, shows the reference flow for one way patient travel to AUH, based on an average travel distance

Table 8.3. Ten largest cities in the Central Denmark Region and their distance to AUH (own table).

City	Distance
Aarhus	6.09 km
Herning	85.27 km
Randers	36.13 km
Horsens	52.32 km
Silkeborg	44.28 km
Viborg	65.82 km
Holstebro	121.11 km
Skanderborg	29.11 km
Ikast	75.12 km
Ringkøbing	133.87 km

within the Central Denmark Region. This distance is calculated using the distances from the ten largest cities in the region, see table 8.3, which results in an average distance of 64.91 km per one-way trip.

The modelled process for one car driving one km is used as an input for the reference flow for patient travel in Table 8.4. As described, patient travel is identically modelled for both surgical procedures and does not contribute to the comparative difference between them.

Table 8.4. LCI table of Patient Travel (own table).

Flow	Unit	Amount	LCI data
Reference flow			
Patient Travel	p	1	Reference flow
Inputs			
Car driving	km	64.91	Table 8.2

Procedure Kit

Table 8.5, provides the LCI for a procedure kit used in both the open procedure and endoscopic procedure. It includes data on material inputs, transport and end-of-life treatment. The procedure kit has a total weight of 3.69 kg including packaging and contains 43 individual products (Appendix H). These products have been disassembled and weighed, the products total material types are summarised and used as material input in this reference flow.

Data for material types are based on hybrid processes modelled for the Danish Regions, to increase the accuracy for each material type. As the procedure kit is produced in Ireland, material type is specified to Ireland and furthermore, transport distances represent the journey from Ireland to Denmark. For end-of-life treatment, it is assumed that all materials are incinerated, representing the most realistic scenario within healthcare.

Anaesthesia Equipment

Table 8.6, provides an overview of the products used in a general anaesthesia procedure. A total of 30 different products are included, accounting for 49 individual units with a combined weight of 2.5 kg, including packaging (Appendix H).

Table 8.5. LCI table of procedure kit (own table).

Flow	Unit	Amount	LCI data
Reference flow			
Procedure Kit	p	1	Reference flow
Inputs			
Aluminium	g	0.66	Aluminium foil
Cardboard	g	2.00	Cardboard
Cellulose fiber	g	2742.00	Cellulose fiber
Packaging paper	g	11.72	Packaging paper
LDPE	g	92.10	PE Low Density
PE	g	385.72	PE Medium Density
PET	g	6.73	PET Granualte
PC	g	2.96	Polycarbonate
PP	g	257.12	PP Granulate
Cotton fibre	g	158.95	Production of cotton fiber, ginning of cotton
Stainless steal	g	7.92	Stainless steel (chromium steel)
Synthetic rubber	g	19.20	Synthetic rubber
Land transport	kgkm	1270.11	122
Sea transport	kgkm	5210.75	124
Incineration: Paper	g	13.72	141
Incineration: Plastics	g	763.83	142
Incineration: Metal	g	8.58	143
Incineration: Textiles	g	2900.95	144

The products are produced in 13 different countries, reflecting material and transport factors form different geographies. For 29 out of the 30 products, physical data, such as weight and material composition were obtained and used directly in the reference flow. One product could not be physically assessed and is therefore represented in Table 8.10 using monetary input under the process for *"Medical Equipment and Accessories and Supplies"*, based on its purchase price.

Material compositions for each product were disassembled and categorised by material type. As the products are produced in different countries, geography specific transport are applied. For end-of-life treatment, it is assumed that all materials are incinerated, representing the most realistic scenario within healthcare.

8.2.1 Single Use Equipment

Table 8.7 presents the reference flow for all single use products used in the open procedure. A total of 115 distinct products are included (Appendix H). However, not all are used in every surgery. Use frequency was analysed across 190 procedures using data provided by SupplyAID. The number of times each product was used was divided by the number of procedures to calculate the average amount of products used per procedure. Summing these averages results in an estimated 18 products used per open procedure. The calculations can be seen in Appendix J.

The products are manufactures in 17 different countries, reflecting variation in material and transport distances. For 61 of the 115 products, physical weight data were obtained and used in the reference flow. The remaining products, for which physical data were

Table 8.6. LCI table of products for anaesthesia equipment (own table).

Flow	Unit	Amount	LCI data
Reference flow			
Anaesthesia Equipment	p	1	Reference flow
Inputs			
Aluminium	g	8.68	Aluminium foil
Cardboard	g	5.00	Cardboard
Non woven polypropylene	g	6.55	Non woven polypropylene
Packaging paper	g	17.10	Packaging paper
HDPE	g	95.00	PE Granulate High Density
LDPE	g	166.95	PE Granulate Low Density
PE	g	64.14	PE Medium Density
PET	g	47.32	PET Granualte
PC	g	69.15	Polycarbonate
PP	g	290.12	PP Granulate
Cotton fiber	g	15.60	Production of cotton fiber
PVC	g	76.94	PVC
Stainless steel	g	1.28	Stainless steel
Synthetic rubber	g	90.30	Synthetic rubber
Land Transport	kgkm	1784.79	122
Sea Transport	kgkm	3891.55	124
Incineration: Paper	g	22.10	141
Incineration: Plastic	g	899.93	142
Incineration: Metal	g	9.96	143
Incineration: Textiles	g	22.15	144

unavailable, are represented using monetary data under the process *"Medical Equipment and Accessories and Supplies"* in Table 8.10, based on purchase price.

For the endoscopic procedure, the same set of 115 products from the open procedure were used as a baseline due to limited data availability. However, observations at AaUH, revealed that four cylinders are required for the endoscopic procedure, compared to only one in the open procedure. Additionally, five single use equipment specific to the endoscopic procedure were identified through conversation with a supplier of endoscopic equipment. Of these, three are used consistently, while the remaining two are used depending on the specific endoscopic approach, transformational or interlaminar, with an average usage per procedure set to 0.75 and 0.25, respectively (Appendix H).

For 66 of the total products, physical weight data was available and used in the reference flow. This includes 20 products with a total weight of 2.91 kg, including packaging. For the remaining monetary input were applied under the same process category as in open procedure. The LCI table for endoscopic procedure can be seen in Appendix F.

Table 8.7. LCI table of Single use Equipment for open procedure (own table).

Flow	Unit	Amount	LCI data
Reference flow			
Single use Equipment	p	1	Reference flow
Inputs			
ABS	g	2.78	ABS
Aluminium	g	1.45	Aluminium foil
Cardboard	g	26.28	Cardboard
Cellulose fiber	g	452.84	Cellulose fiber
Copper	g	5.94	Copper
Latex	g	160.68	Latex
Packaging paper	g	137.70	Packaging paper
PE	g	304.03	PE Medium Density
LDPE	g	105.97	PE Granulate Low Density
HDPE	g	70.94	PE Granulate High Density
PET	g	27.17	PET Granulate
PC	g	4.28	Polycarbonate
PP	g	33.26	PP Granulate
Production of cotton fiber	g	15.88	Production of cotton fiber
PVC	g	9.61	PVC
Simple electronics	g	3.20	Simple electronics
Stainless steel	g	6.62	Stainless steel
Synthetic rubber	g	7.25	Synthetic rubber
Chemicals	g	58.24	63
Land transport	kgkm	1527.47	122
Sea transport	kgkm	7352.59	124
Incineration: Paper	g	163.99	141
Incineration: Plastic	g	725.97	142
Incineration: Metal	g	17.22	143
Incineration: Textiles	g	468.72	144

8.2.2 Reusable Instruments

Table 8.8 presents the reference flow for all reusable instruments required for the open procedure. The instrument set consists of 41 stainless steel instruments, with a total weight of 5.54 kg (Appendix H). The instruments were weighted collectively in a metal tray after surgery and prior to sterilisation, as individual weighing was not permitted due to sterilisation safety. The aggregated mass therefore represents the full set of instruments used per procedure, and the material type is generalised and set to be 100% stainless steel.

All instruments are assumed to be manufactured in Pakistan, and the corresponding geography "Rest of Middle East" is applied for both material sourcing and transport distance.

For the endoscopic procedure, two reusable instruments are used. Based on conversations with the supplier of endoscopic equipment, 75% of procedures are preformed using the transformational approach and 25% using the interlaminar approach. Accordingly, the reference flow includes 0.75 of the transforaminal set and 0.25 of the interlaminar set, which has a combined weight of 9.50 kg (Appendix H). All instruments are manufactured in Germany, and the corresponding geography is applied for both material and transport distances. The weight data for the endoscopic instrument sets were provided directly by the supplier, and it was therefore not possible to obtain physical measurements in the same manner as for the open procedure. For both procedures, the total instrument weight is divided by 1,000 uses to reflect the assumed lifespan of the instruments. This results in a weight of reusable instruments, per use of 5.54 g for open procedure and 9.50 g for the endoscopic procedure.

Sterilisation is included in the reference flow for both procedures and includes electricity, water and industrial detergent consumption per sterilisation. These data are based on internal regional estimates from a sterilisation tool, and are modelled identically for both procedures, as no additional data specific to endoscopic sterilisation were available. For end-of-life treatment, it is assumed, that the instruments are incinerated after use, representing the most realistic scenario for the healthcare sector. The LCI tables for endoscopic procedure can be seen in Appendix F.

Table 8.8. LCI table of Reuseable Equipment for the open procedure (own table)

Flow	Unit	Amount	LCI data
Reference flow			
Reusable instruments	p	1	Reference flow
Inputs			
Stainless steel	g	5.54	Stainless steel
Land transport	kgkm	0.01	122
Sea transport	kgkm	0.07	124
Electricity	MJ	113.40	Electricity mix
Water	m^3	0.28	113
Industrial detergent	g	152.40	Industrial detergent
Incineration: Metal	g	5.54	143

8.2.3 Medico-Technical Instruments

Table 8.9 presents the reference flow for the medico-technical instruments used in an open procedure. A total of nine instruments were identified, with purchase data available for eight and physical data, including weight and energy consumption, available for five (Appendix H). Based on input from Madsen (2025), the expected service life of these medico-technical instruments is on average eight years. In 2024, the Department of Brain and Spine Surgery at AUH, treated 2,876 patients, resulting in 23,008 procedures over the medico-technical instruments' service life.

Unlike the open procedure, a surgical microscope is not used in the endoscopic procedure. Instead, nine additional instruments specific to the endoscopic setup are included. The aggregated weight of the instruments is 1,093 kg, corresponding to 0.05 kg per procedure. The total cost of 581.212 DKK2024 results in an average cost of 25.26 DKK2024 per procedure. Electricity consumption is calculated based on an average surgery time of 85 min, calculated to be 87.27 MJ per procedure, based on the combined energy use of five instruments. Four of the instruments account for 10.39 MJ, while the remaining consumption stems for the x-ray machine, the calculation can also be seen in more detail in Appendix H.

Standby power:

$$15\text{ kW} \cdot \frac{85\text{ min}}{60} \cdot 3.6 = 76.50\text{ MJ}$$

Imaging pulses:

$$25\text{ kW} \cdot \frac{15\text{ s}}{3600} \cdot 3.6 = 0.38\text{ MJ}$$

For the endoscopic procedure, 16 medico-technical instruments were identified through observations at AaUH and is further specified by Madsen (2025). Physical data were available for ten instruments, while the remaining six are represented using monetary input. The total weight of the ten instruments is 745 kg, corresponding to 0.03 kg per procedure. The total cost of 535,000 DKK 2024 results in an average cost of 29.12 DKK2024 per procedure for medico-technical instruments. Electricity consumption is calculated based on an average surgery time of 45 min. The combined energy use of nine instruments, excluding x-rays, is 4.0 MJ. The x-ray machine's energy use is calculated as (Appendix H):

Standby power:

$$15\text{ kW} \cdot \frac{45\text{ min}}{60} \cdot 3.6 = 76.50\text{ MJ}$$

Imaging pulses:

$$25\text{ kW} \cdot \frac{30\text{ s}}{3600} \cdot 3.6 = 0.38\text{ MJ}$$

This results in a total electricity use of 45.25 MJ per procedure, reflecting the precision required when navigating with an endoscope. The increased number of x-ray images used for the endoscopic procedure highlights the greater need for accurate instrument placement.

For both procedures, the total electricity consumption from medico-technical instruments is subtracted from the overall electricity in the procedure pathway, in Table 8.10, to avoid double counting. Cost data are used as monetary input in the respective LCI tables, for the pathway of the procedures. As The origin of the instruments could not be determined, Denmark is assumed as the production location for both procedures. The LCI tables for the endoscopic procedure can be seen in Appendix F.

Table 8.9. LCI table of the medico-technical instruments used for the open procedure (own table).

Flow	Unit	Amount	LCI data
Reference flow			
Medico-technical instruments	p	1	Reference flow
Inputs			
Production of Medico-technical instruments	kg	0.05	88
Land transport	kgkm	16.37	122
Electricity	MJ	87.27	Electricity mix

8.2.4 Patient Pathway

Table 8.10 presents the reference flow for a complete pathway for treatment of a lumbar disc herniation by open procedure. The patient pathway using endoscopic procedure can be seen in Appendix F. The reference flow if defined for one patient undergoing surgery and a hospital admission period, 36 hours for the open procedure and 19.2 hours for the endoscopic procedure. The shorter admission time and reduced electricity consumption from medico-technical instruments in the endoscopic procedure reflects its less invasive nature and shorter surgery time. Specifically, electricity consumption from medico-technical instruments are 87.27MJ for the open procedure and 45.25 MJ for the endoscopic procedure. These values are, as explained in LCI for medico-technical instruments, subtracted from the total electricity consumption to avoid double counting. For both procedures, the following data are calculated as follows:

Electricity consumption per patient:

$$\frac{1,035.12 \text{ MWh}/2024}{2,876 \text{ Patients}} \cdot 3,600 = 1,295.70 \text{ MJ per patient}$$

District heating per patient:

$$\frac{575.46 \text{ MWh}/2024}{2,876 \text{ Patients}} \cdot 3,600 = 720.33 \text{ MJ per patient}$$

Water consumption per patient:

$$\frac{8,684 \text{ m}^3}{2,876 \text{ Patients}} = 3.02 \text{ m}^3$$

After subtracting the electricity used by medico-technical instruments, the total energy consumption per procedure is:

Open procedure:

$$(1,295.70 + 720.33) - 87.27 = 1,928.97 \text{ MJ}$$

Endoscopic procedure:

$$(1,295.70 + 720.33) - 45.25 = 1,970.78 \text{ MJ}$$

Monetary inputs are extracted from the regional BI portal for year 2024. The data is categorised using UNSPSC codes and connected to the corresponding EXIOBASE categories (Appendix D and Table D1). For the endoscopic procedure, monetary values are further adjusted to reflect procedure specific costs related to equipment, admission expenses, and employee expenses. The reference flow representing the physical inputs for patient travel, procedure kit, anaesthesia equipment, single use equipment, reusable instruments, and medico-technical instruments are included in the complete pathway for both procedures. The LCI table for endoscopic pathway can be seen in Appendix F.

Table 8.10. LCI table of Pathway (own table).

Flow	Unit	Amount	LCI data
Reference flow			
Pathway	p	1	Reference flow
Inputs			
Medical Equipment [...]	DKK2024	192.00	90
Healthcare Services	DKK2024	171.25	139
Transportation and Storage [...]	DKK2024	49.54	122
Travel and Food [...]	DKK2024	48.54	120
Education and [...]	DKK2024	34.79	138
Food Beverage and [...]	DKK2024	32.11	43
Financial and [...]	DKK2024	31.78	131
Apparel and Luggage [...]	DKK2024	27.36	48
No match	DKK2024	14.56	87
Personal and [...]	DKK2024	13.61	162
Information Technology [...]	DKK2024	12.87	89
Laboratory and Measuring [...]	DKK2024	12.74	90
Drugs and Pharmaceutical[...]	DKK2024	1235.39	63
Politics and Civic [...]	DKK2024	10.48	162
Farming and Fishing [...]	DKK2024	6.97	13
Furniture and Furnishings	DKK2024	5.55	93
Domestic Appliances [...]	DKK2024	4.99	88
Material Handling and [...]	DKK2024	4.48	86
Electrical Systems [...]	DKK2024	4.05	88
Financial and [...]	DKK2024	3.87	129
Management and Business [...]	DKK2024	3.52	137
Musical Instruments [...]	DKK2024	3.46	50
Organisations and Clubs	DKK2024	3.34	137
Politics and Civic [...]	DKK2024	3.21	137
Published Products	DKK2024	3.15	55
Editorial and Design [...]	DKK2024	3.04	55
Office Equipment [...]	DKK2024	2.90	87
Cleaning Equipment [...]	DKK2024	2.85	63
Public Utilities [...]	DKK2024	2.72	108
National Defence [...]	DKK2024	2.08	137
Land and Buildings [...]	DKK2024	1.71	114
Plants and Animal [...]	DKK2024	1.37	7
Industrial Production [...]	DKK2024	0.94	162
Power Generation [...]	DKK2024	0.61	108
Distribution and [...]	DKK2024	0.51	86
National Defence [...]	DKK2024	0.49	137
Paper Materials and Products	DKK2024	0.30	54
Building and Facility [...]	DKK2024	0.23	114
Chemicals [...]	DKK2024	0.21	63
Manufacturing Components[...]	DKK2024	0.15	86
Service Industry [...]	DKK2024	0.14	86
Resin and Rosin [...]	DKK2024	0.13	64
Tools and General Machinery	DKK2024	0.01	86
Industrial Manufacturing [...]	DKK2024	0.01	86
Structures and Building [...]	DKK2024	0.00	114
Unspecified	DKK2024	0.00	162
Industrial Cleaning Services	DKK2024	0.00	63
Engineering and Research [...]	DKK2024	0.00	134
Employee Expense	DKK2024	8740.00	139
Admission Expense	DKK2024	5250.00	139
Medico-technical instruments	DKK2024	25.26	88
Medico-technical instruments	p	1	Table 8.9
Procedure kit	p	1	Table 8.5
Patient travel	p	4	Table 8.4
Single use equipment	p	1	Table 8.7
Anaesthesia equipment	p	1	Table 8.6
Reusable instruments	p	1	Table 8.8
Water	m3	3.02	113
Electricity	MJ	1208.43	Electricity mix
District heating	MJ	720.33	112

8.3 Life Cycle Impact Assessment

The aim of the LCIA is to translate the LCI data into environmental impacts to evaluate the performance of the two different surgical procedures. To assess these environmental impacts, the method *"Stepwise 2006 V1.07 / Europe95 person / EUR excl. biogenic C"* was selected due to its compatibility with EXIOBASE. The impact category assessed is global warming, which is specifically requested by the Department for Brain and Spine Surgery.

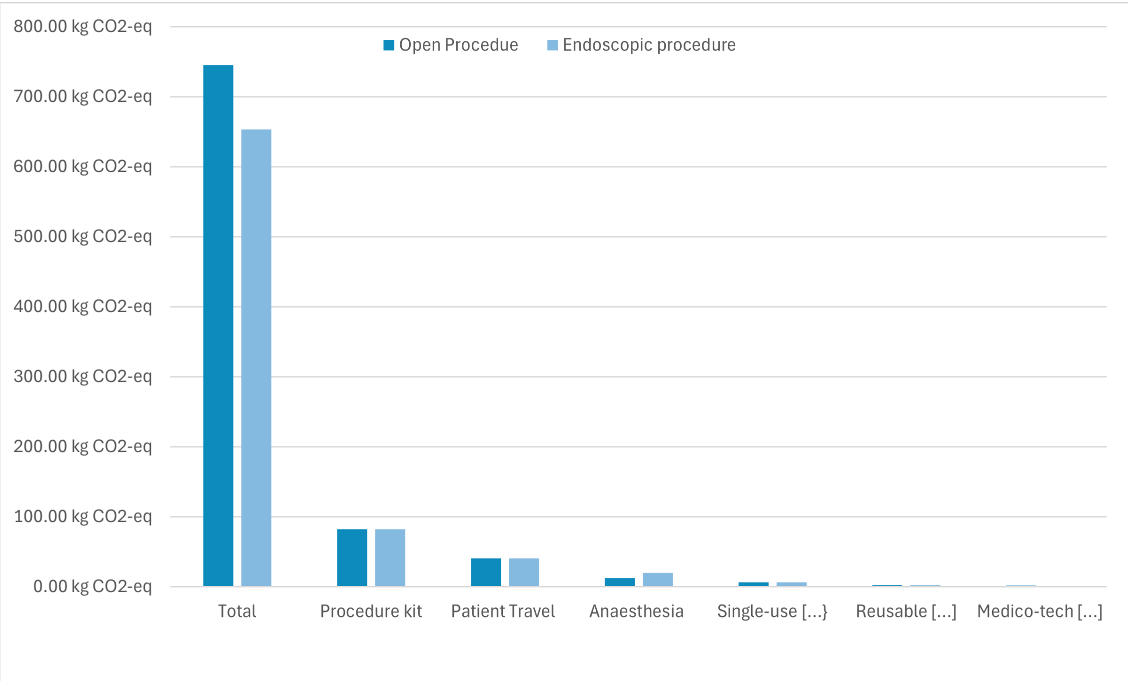
In the following sections, the results of the impacts assessment are presented based on the selected categories. Following this, sensitivity analyses are conducted to evaluate the findings and examine how different factors may influence the overall conclusion.

8.3.1 Results

The environmental impact results for each of the surgical procedures, including all collected data and processes in categories, are presented in Table 8.11 and illustrated in Figure 8.2.

Table 8.11. Contribution by category (own table).

Conributing category	Open surgery	Endoscopic surgery	Unit
Total	**745.09**	**690.70**	**kg CO_2-eq**
Procedure Kit	82.18	82.18	kg CO_2-eq
Patient travel	40.23	42.98	kg CO_2-eq
Single use equipment	12.24	19.65	kg CO_2-eq
Anaesthesia	6.00	6.00	kg CO_2-eq
Reusable instruments	2.37	2.36	kg CO_2-eq
Medico-technical instruments	1.66	0.93	kg CO_2-eq



Figur 8.2. Graph over contribution by category (own figure).

According to the overall results, the open procedure has a total emission of 745.06 kg CO_2-eq, whereas the endoscopic procedure has an emission of 690.70 kg CO_2-eq, resulting in a reduction of 54.39 kg CO_2-eq, or 7% when switching to the endoscopic procedure.

The most notable differences in environmental impact between the two procedures are in the two categories of single use equipment and medico-technical instruments. The endoscopic procedure results in higher total CO_2-eq from single use equipment due to the inclusion of additional products and thereby increased material use. Conversely, the open procedure shows a higher impact from medico-technical instruments. This is primary due to the longer surgery time, which results in increased electricity consumption by the medico-technical instruments. The difference is therefore seen in for example the use of the endoscope or the increased estimation of X-ray scans.

To better understand the environmental impact of each procedure, Table 8.12 presents the top ten contributing categories for the open procedure and compares their impact with the endoscopic procedure. The table includes the absolute emissions for both procedures as well as the percentage difference when transitioning from open to endoscopic procedure. Categories with a 0 % difference indicate no change in impacts at their input remain the same between the two procedures.

Table 8.12. Table overview of top ten impact contributor categories contributing to the total environmental impact of the Open procedure (Own table).

Conributing category	Open procedure [kg CO_2-eq]	Endoscopic procedure [kg CO_2-eq]	Difference [%]
Admission Expenses	**135.12**	**67.56**	**50**
Employee Expenses: Anaesthesia nurses	105.18	105.18	0
District Heating	102.20	102.20	0
Procedure kit	82.18	82.18	0
Employee Expense: Surgeons	79.52	79.52	0
Drugs and Pharmaceutical[...]	73.49	73.49	0
Patient Travel	42.98	42.98	0
Employee Expenses: Porter	40.23	40.23	0
Electricity	**17.13**	**17.73**	**-3**
Single use equipment	**12.24**	**19.65**	**-61**

The results show that admission expenses are the largest contributor to the difference, with a 50% reduction in the endoscopic procedure due to shorter hospital stays. Other categories such as electricity and single use equipment also show a change, with electricity increasing with 3%, and single use equipment increasing with 61%, though the absolute difference is relative small by only 0.60 kg CO_2-eq for electricity and by 7.41 kg CO_2-eq for single use equipment.

Although the total electricity consumption appears higher in the endoscopic procedure compared to the open procedure, this difference does not reflect a higher actual energy demand. Instead, it is a result of how electricity is allocated in the model. In both procedures, the total overall electricity consumption is calculated to be 1,295.70 MJ, However, electricity used by medico-technical instruments from both procedures is subtracted from the total overall electricity input in the pathway to avoid double counting. Since the endoscopic procedure uses less electricity for medico-technical instruments, due to shorter surgery time, less electricity is subtracted from the total overall electricity use. This results in a slightly higher electricity input in the endoscopic pathway. This modelling highlights an important insight, as although the total overall electricity use is constant, the use of medico-technical instruments in the endoscopic procedure can lead to a lower electricity demand per procedure. The apparent increase in electricity is therefore not a real increase, but a consequence of an allocation choice.

8.3.2 Sensitivity Analysis

Within the framework of this LCA study, a comprehensive amount of data has been collected by different methods, which entails uncertainty, assumptions, and simplifications. This sensitivity analysis will test the robustness of the results by varying key parameters that have been used in this study despite uncertainty. The uncertainty of the results will therefore be tested to show the robustness of the results. In this way the sensitivity analysis brings the theoretical knowledge closer to a real-world framework where uncertainty and sensitivity applies, especially within hospital settings. This provides insights in how variables may affect the overall conclusions and helps identify which elements of the LCA model influence the outcome.

EXIOBASE Categories

The first sensitivity analysis analyses the influence of background data on the overall results by comparing the use of hybrid processes, for more specific material types, with EXIOBASE processes, using more general material types.

The sensitivity analysis for background data was conducted in two steps:

1. **EXIOBASE material types:** All material hybrid processes were replaced with corresponding EXIOBASE categories, while maintaining the original geographic origin.
2. **EXIOBASE only:** All monetary data were aggregated under a single EXIOBASE category *"139 Health and social work (85) DK (product market, monetary units, purchaser price)"*.

In the EXIOBASE only sensitivity analysis, two types of data were included in the aggregation. First, all monetary data already represented in the baseline LCA. Secondly, for processes where physical data were used in the baseline. The purchase price for the equipment and instruments were applied to convert them into monetary units. These were then added to the total. This ensured that all products still were accounted for. This resulted in a total cost of 17,876 DKK2024 for the open procedure and 13,436 DKK2024 for the endoscopic procedure.

The results are presented in Table8.13. When replacing only the material categories, the total environmental impact decreased from 745.09 kg CO_2-eq to 722.03 kg CO_2-eq for the open procedure, and from 690.70 kg CO_2-eq to 660.24 kg CO_2-eq for the endoscopic procedure. This confirms that hybrid processes contribute to a higher impact, but the open procedure still has a higher impact than the endoscopic procedure.

In the EXIOBASE only scenario, the total impact for both procedure was significantly reduced, by 38.3% for the open procedure and 49.9% for the endoscopic procedure, compared to the baseline. The reduction highlights the limitations using aggregated economic data alone, as it underestimates the environmental impacts. The EXIOBASE category *"139 Health and social work (85) DK"*, is a broad, average based representation of healthcare services, and does not account for specific characteristics of the two surgical procedures.

More specifically, this approach does not reflect the quantity of materials required for each procedure, the type of origin of those materials or the transport distances. It also omits the procedure specific electricity consumption and end-of-life treatment of materials. As a result, emissions are excluded and the total environmental impact is underestimated, and therefore it does not provide a reliable estimate of the actual environmental impact.

Table 8.13. Sensitivity analysis on hybrid vs EXIOBASE processes. EXIOBASE material refer to the sensitivity analysis where all materials have been converted from hybrid processes to EXIOBASE processes, and EXIOBASE only refer to the aggregation of all data in monetary units under the EXIOBASE category "139_Health and social work" (own table).

Sensitivity	Open procedure	Endoscopic procedure	Unit
Baseline	745.09	690.70	kg CO_2-eq
EXIOBASE material types	722.03	660.24	kg CO_2-eq
EXIOBASE only	460.00	346.00	kg CO_2-eq

End-of-life Treatment

As a third sensitivity analysis, the end-of-life treatment stage was investigated. In the baseline LCA, all materials were modelled with incineration as the end-of-life treatment. Although the Central Denmark Region has implemented a waste sorting system, this is not always realistic in practice. In hospital settings, time pressure and strict hygiene protocols often hinder effective sorting. Furthermore, many medical equipments are single use equipment designed in a complex to fulfil its function, but often hinder the ability to be sorted correctly, as it consists of various types of materials and cannot be disassembled, in a way that enables reprocessing. For these reasons, incineration was chosen as the most realistic end-of-life treatment in the baseline scenario.

However, since increased recycling is an environmental objective within the Central Denmark Region, this sensitivity analysis explores the potential reduction of impacts if the existing recycling system is used more consistently. Specifically, the incineration of paper, plastic, and metals is replaced with corresponding reprocessing processes. Textiles were excluded from the analysis, as recycling of textiles is not considered realistic in this context. Table 8.14 provides an overview of the process an their replacement for this scenario.

Table 8.14. Disposal scenario showing which incineration processes have been exchanged and with which recycling or reprocessing prosesses (own table).

Incineration scenario	Recycling or reprocessing scenario
141 Incineration of waste: Paper	_53 Re-processing of secondary paper [...]
142 Incineration of waste: Plastic	_60 Re-processing of secondary plastic [...]
143 Incineration of waste: Metals [...]	_73 Re-processing of secondary steel [...]
144 Incineration of waste: Textiles	144 Incineration of waste: Textiles

The results of this sensitivity analysis are presented in Table 8.15. When converting from a scenario of incineration to recycling for paper, plastic, and metals, the total environmental impact decreases for both procedures. The open procedures is reduced from 745.09 kg CO_2-eq to 737.90 kg CO_2-eq, and the endoscopic procedure from 690.70 kg CO_2-eq to

676.00 kg CO_2-eq. This corresponds to a reduction of approximately 0.96% for the open procedure and 2.13% for the endoscopic procedure.

Table 8.15. Sensitivity on disposal scenario converting from incineration to recycling (own table).

Sensitivity	Open procedure	Endoscopic procedure	Unit
Baseline	750.09	690.70	kg CO_2-eq
Recycling	737.90	676.00	kg CO_2-eq

The results show that a more consistent recycling practice could contribute to reducing the environmental impact of both surgical procedures, although they constitute a relatively minor difference compared to the result from the incineration scenario.

Number of Reuses for Reusable instruments

As the final sensitivity analysis, the number of reuses for reusable instruments is investigated. In the baseline LCA, all reusable instruments are modelled with an estimated total of 1,000 reuses. This sensitivity analysis explores how variations in this assumption affect the overall environmental impact. Specifically, scenario with 1 use, 500 reuses and 2,000 reuses are analysed to assess the robustness of the baseline. The results are presented in Table 8.16.

Table 8.16. Sensitivity analysis on number of reuses of reusable instruments with respectively 1, 1,000, and 2,000 reuses. Baseline is 1,000 reuses (own table).

Sensitivity	Open procedure	Endoscopic procedure	Unit
Baseline	745.09	690.70	kg CO_2-eq
1 use	803.42	731.93	kg CO_2-eq
500 uses	745.15	683.33	kg CO_2-eq
2000 uses	745.06	683.26	kg CO_2-eq

This result shows that increasing the number of reuse from 1,000 to 2,000 has an effect on the overall environmental impact. However, if the instruments are only used once, the total impact increases by approximately 7.8% for the open procedure and 6% for the endoscopic procedure. This indicates that while the baseline assumption of 1,000 reuses is robust, a reduction in reuse would increase the environmental impact. Consequently, increasing the number of reuses beyond 1,000 only results in marginal reductions.

Results of Sensitivity Analysis

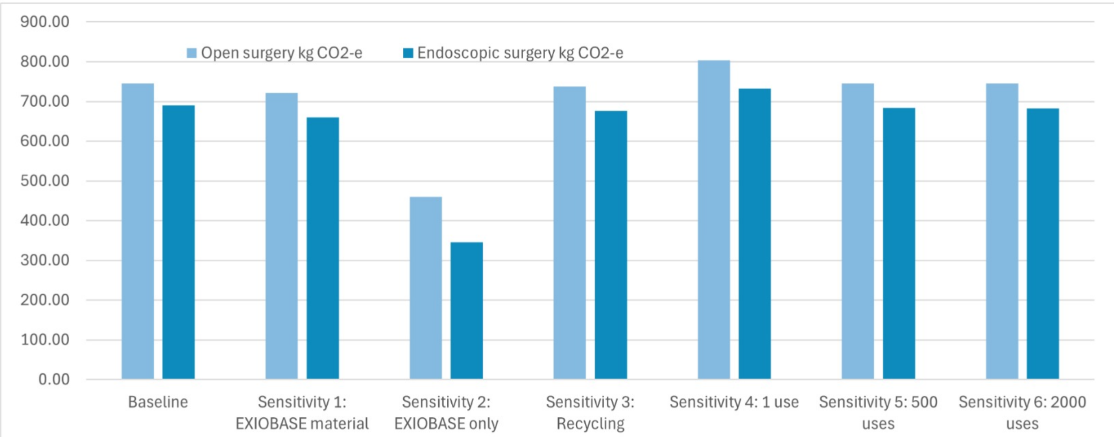
To conclude the sensitivity analysis, all included analyses are compared with the baseline results, as illustrated in Figure 8.3.

The sensitivity analysis demonstrates that none of the sensitivity analyses conducted have an influence on the conclusion of the overall environmental impact results. The endoscopic procedure consistently results in a lower total environmental impact compared to the open procedure. This finding remains valid across changes in background data, end-of-life treatment, and the number of reuses for reusable instruments.

Among the analyses, the only scenario that significantly affects the absolute environmental impact is the EXIOBASE only scenario. This leads to a reduction in calculated emission by 38.3% for the open procedure and 49.9% for the endoscopic procedure. This approach fails to account for specific contributors such as single use equipment, reusable instruments etc. As a result the environmental impact of the two procedures are underestimated. The sensitivity analysis however concludes that endoscopic procedures are lower in emissions compared to open procedures, in conformity with the overall results of the LCA.

The end-of-life treatment scenario shows a reduction in environmental impacts, when converting from incineration to recycling. The open procedure is reduced by 0.96% and the endoscopic procedure by 2.13%. This suggests, that while improved recycling practices can lower the environmental impact, it does not affect the overall impact of the two procedures drastically.

The sensitivity analyses confirms that the baseline assumption of 1,000 reuses is robust. Increasing the number of reuses to 2,000 reuses has an insignificant influence on the total CO_2-eq emissions, while reducing it to 500 reuses also shows a minimal change. However, if instruments are only used once, the environmental impact increases with 7.8% for the open procedure and 6% for the endoscopic procedure. This highlights the importance of maintaining reuse practices but also shows that the analysis is not sensitive to changes in reuse frequency, whether reuses are doubled or halved.



Database	Hybrid/EXIOBASE	Hybrid/EXIOBASE	**EXIOBASE**	Hybrid/EXIOBASE	Hybrid/EXIOBASE	Hybrid/EXIOBASE	Hybrid/EXIOBASE
Materials	Hybrid	**Hybrid/EXIOBASE**	**None**	Hybrid	Hybrid	Hybrid	Hybrid
Disposal	Incineration	Incineration	**None**	**Recycling**	Incineration	Incineration	Incineration
Number of reuses	1000	1000	**None**	1000	**1**	**500**	**2000**

Figur 8.3. Overview of conducted sensitivity analyses and their influence on the overall environmental impact compared with the baseline. Database refers to which database is utilised, disposal refers to the chosen end-of-life treatment scenario, and reuses refer to the number of reuses for reusable instruments. Change in data is highlighted in red (own table).

In conclusion, the LCA results are shown to be robust across a range of variations. The most critical factor influencing the total environmental impact, is the choice of background data.

8.4 Interpretation

Following the sensitivity analysis, this section provides a broader interpretation of the results, a critical review of the methodological choices and an analysis of the limitations of the LCA.

The results of this LCA indicates that the endoscopic procedure consistently results in an overall lower environmental impact compared to the open procedure. This conclusion is robust across all sensitivity scenarios investigated, including variations in background data, end-of-life treatment, and the number of reuses for reusable instruments.

The total environmental impact is calculated to be 745.09 kg CO_2-eq for the open procedure and 690.70 kg CO_2-eq for the endoscopic procedure. The results and their contributing categories are again presented in Table 8.17.

Table 8.17. Contribution by category

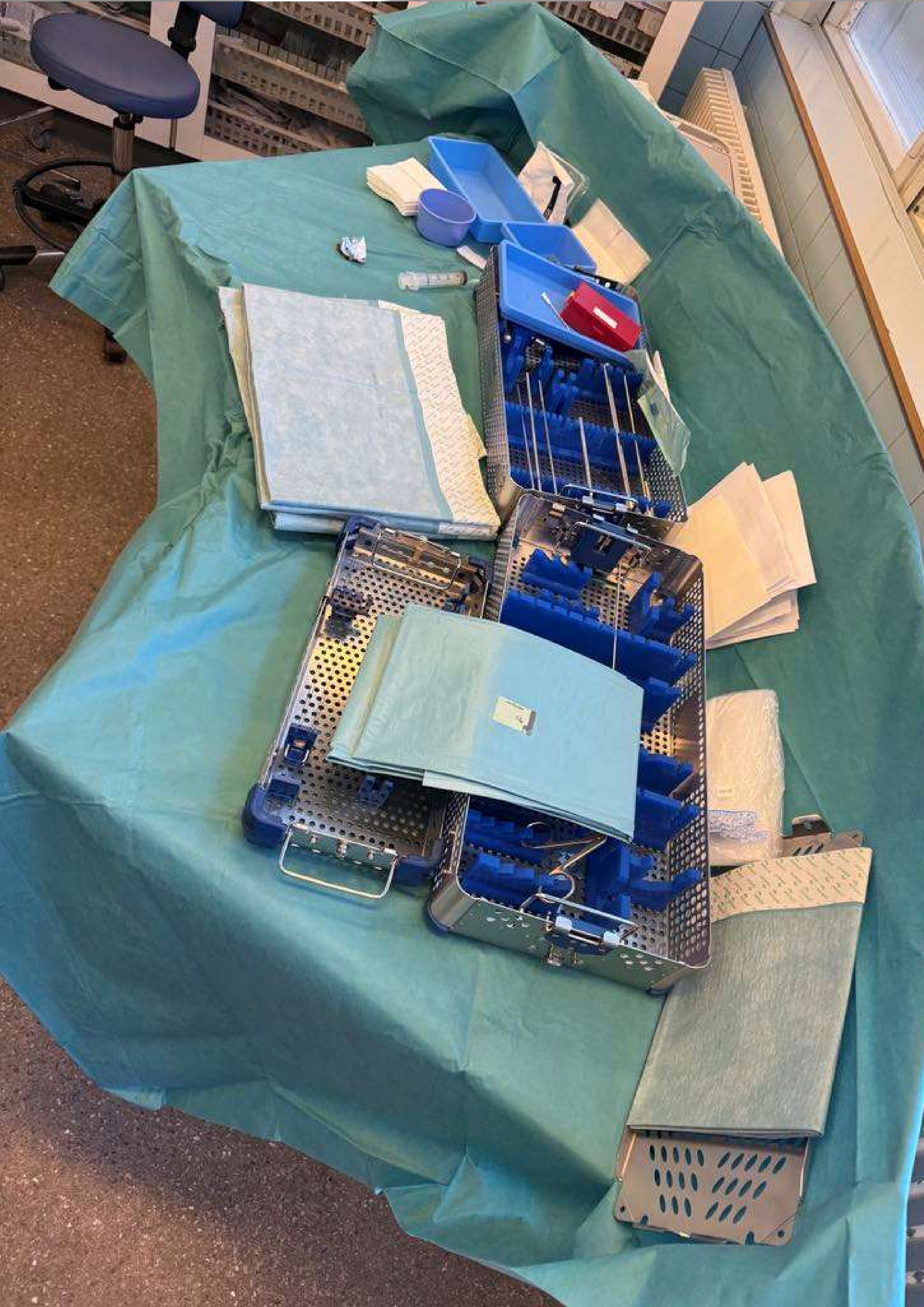
Conributing category	Open surgery	Endoscopic surgery	Unit
Total	**745.09**	**690.70**	**kg CO_2-eq**
Procedure Kit	82.18	82.18	kg CO_2-eq
Patient travel	40.23	42.98	kg CO_2-eq
Single use equipment	12.24	19.65	kg CO_2-eq
Anaesthesia	6.00	6.00	kg CO_2-eq
Reusable instruments	2.37	2.36	kg CO_2-eq
Medico-technical instruments	1.66	0.93	kg CO_2-eq

Although the endoscopic procedure appears to have a higher electricity impact, this is not due to higher electricity consumption. In both procedures, the total electricity consumption for the patient pathway is the same.

However, two limitations are identified. The most notable is the exclusion of post discharge activities, such as rehabilitation, which as told by Bjarkam and Oettingen, differ between the two procedures (Appendix A and C). Additionally, the assumed number of reuses for instruments may vary in practice, and while sensitivity analysis showed this assumption to be robust, deviations could influence the number of reuses in practical settings. Such deviations may occur if instruments are worn out earlier than expected or lost during surgery. However, this is considered relatively rare, as instruments are typically checked multiple times, both in the operating room and during the sterilisation process (Elankanathan, 2025).

Other limitations identified are data availability, as some products are modelled using monetary data due to lack of physical data. This is particularly the case for the endoscopic procedure, as they at AaUH does not have a data system alike SupplyAIS at AUH. This made it more difficult to identify exactly which single use equipment were used during the endoscopic procedure. As a result, the single use equipment for the endoscopic procedure is primarily based on the single use equipment from the open procedure, inputs from the supplier, and observation.

Despite the limitations mentioned above, the study provides a robust and transparent comparison of two surgical procedures and offers insights for decision makers aiming to reduce the environmental impact for treatment of lumbar disc herniation.



Second Analysis - Reduction Opportunities 9

This chapter will address the second sub-question:

How can the environmental impacts of treating lumbar disc herniation be reduced?

As mentioned in Chapter 2, the endoscopic procedure has been presented with a possibility to increase from three to four surgeries per day, if it is possible to perform the surgery under regional or local anaesthesia, according to Oettingen (Appendix A). As the Department of Brain and Spine Surgery will be able to perform more lumbar disc herniation surgeries with this initiative, the reduction will be investigated in order to assess the reduction potential.

9.1 Calculation

The reduction potential in performing four instead of three lumbar disc herniation surgeries per day is based on the assumption that the endoscopic surgical procedure will require less time for surgery, and therefore it is possible to conduct a fourth procedure in the time that is saved by converting from open procedure to endoscopic procedure (Appendix A).

9.1.1 Electricity & District Heating

The main parameter that has an influence when increasing the amount of endoscopic procedure from three to four is the amount of electricity and district heating required to perform a surgery. This is based on the assumption that the time in surgery is reduced and thereby also the electricity consumed during surgery. Below is a step by step walk-through of how this calculation is made, which can also be seen in more detail in Appendix H.

Step 1:
The first step of conducting an LCA based on an increase from three to four patients per day is to determine total amount of surgeries and the number of lumbar disc herniation surgeries performed at the Department of Brain and Spine Surgery in 2024. An overview is provided in Table 9.1.

Table 9.1. Overview of total number of patients and lumbar disc herniation patients in 2024 at AUH's Department of Brain and Spine Surgery (own table).

Total amount of surgeries 2024	Lumbar disc herniation surgeries 2024
2,876	164

The number of lumbar disc herniation surgeries performed in a year is therefore divided by three and multiplied by four to find the new number of total lumbar disc herniation surgeries in a year;

$$164 * 1.33 = 219$$

There are now 219 lumbar disc herniation patients per year at AUH's Department of Brain and Spine Surgery. This is then added to determine the total amount of patients;

$$2,876 + (219 - 164) = 2,931$$

Step 2:
It is assumed that an increase in patients from 2,876 to 2,931 will not conclude a significant increase in the Department of Brain and Spine Surgery's total procurement per year, except for the categories for *"Medical Equipment and Accessories and Supplies"* and *"Drugs and Pharmaceutical Products"*. This is based on the assumption that a surgery will still require a cost of the two categories, but will conversely not require further expenditures on e.g. office machinery, insurance services, etc. All other categories than *"Medical Equipment and Accessories and Supplies"* and *"Drugs and Pharmaceutical Products"* have been divided by the new number of patients for a scenario with four endoscopic surgeries per day, see Table 9.2 and Appendix F.

Table 9.2. Expenditures for respectively three and four endoscopic surgeries per day at the Department of Brain and Spine Surgery (own table).

	3 surgeries per day	**4 surgeries per day**
Expenditures per patient in DKK	2,042.01	2,003.69

The calculation shows a slight saving in the overall procurement data required to perform an endoscopic procedure when converting from three to four surgeries.

Step 3:
When converting from three to four endoscopic procedures per day, this also influences the energy consumption per surgery. The department has a daily total energy consumption that can now be divided by 2,931 instead of 2,876 surgeries, as supporting services and energy consuming activities will continue regardless of whether three or four surgeries are conducted. It can be argued, that more consumption could take place when increasing the number of surgeries per day, due to the increase in total activity. However, this is estimated to be of minor influence of the total consumption for the department.

The Department of Brain and Spine Surgery's yearly consumption based on year 2024 can be seen in Table 9.3.

Table 9.3. Energy and water consumption by the Department of Brain and Spine Surgery in 2024 (own table).

Electricity and ventilation	1,035.12	MWh
District heating	575.46	MWh
Water	8684.6	m3

It can be assumed that electricity and district heating will have approximately the same consumption on a daily basis, but the water consumption, however, can be influenced by the amount of patients as washing and cleaning in connection with a surgery has a significant impact in the water consumption. Therefore, electricity, ventilation, and district heating are set as a fixed yearly value. However, water consumption is estimated as a variable that depends on the number of patients per year. The calculation of this can be seen in Appendix H. Below is a calculation of electricity and ventilation, district heating, and water consumption in connection with one patient for the scenarios of respectively three and four endoscopic procedures per day.

Electricity and ventilation consumption:
3 surgeries per day:

$$1,035.12/2,876 * 3,600 = \underline{1,295.7MJ}$$

4 surgeries per day:

$$0.275998 * 3,600 = \underline{993.48MJ}$$

District heating:
3 surgeries per day:

$$575.46/2,876 * 3,600 = \underline{720.33MJ}$$

4 surgeries per day:

$$0.156128 * 3,600 = \underline{562.06m^3}$$

Water:
The same for both three and four surgeries per day:

$$127.81/2,876 = \underline{3.02m^3}$$

9.1.2 Employee Expenditures

Another process that is changed to convert from three to four endoscopic surgeries per day, is the expenditures for employees, hereunder surgents, porters, and anaesthesia nurses. According to Oettingen, it will result in less economic expenditures for employees, see Table 9.4.

Table 9.4. Overview of expenditures for conducting three and four surgeries for respectively anaesthesia nurses, surgents, and porters shown in percentages (own table).

Expenditures		
Category	**3 surgeries per day**	**4 surgeries per day**
Anaesthesia	100 %	59 %
Surgent	100 %	75 %
Porter	100 %	75 %
Total	100 %	67 %

The results of converting from three to four endoscopic surgeries per day show an overall cost saving of employee expenditures of 33%. The estimated cost per surgery is provided by Oettingen, and can be seen in Appendix A in Table A1. The specific cost is included in the LCA model contributing to the overall results.

The total calculation and all inputs required to conduct this comparative LCA assessing the conversion from three to four surgeries can be seen in Appendix H and the results can be seen in more detail in Appendix I.

9.1.3 Results

The overall results show that with an increase from three to four endoscopic surgical procedures per day, the environmental impact per procedure is reduced, see Table 9.5. This reduction is primarily due to improved utilisation of electricity and district heating, which is assumed have the same consumption used throughout the department regardless of whether three or four endoscopic procedures are performed per day. The supporting facilities and activities surrounding the surgeries in the department can have a slight change when performing an extra surgery, but it is not assumed to have a significant influence, as it will not require much further of the surrounding infrastructure to secure capacity of converting from three to four surgeries per day. Within hospital settings, it is realistic to assume that lighting, HVAC systems, and other energy consuming activities remain active or in standby mode during the day.

Table 9.5. Total results of conducting respectively three or four endoscopic surgeries per day. The results show the concluded environmental impact per endoscopic surgery (own table).

Endoscopic procedure 3 surgeries per day	Endoscopic procedure 4 surgeries per day	Unit
690.7	590.2	kg CO_2-eq

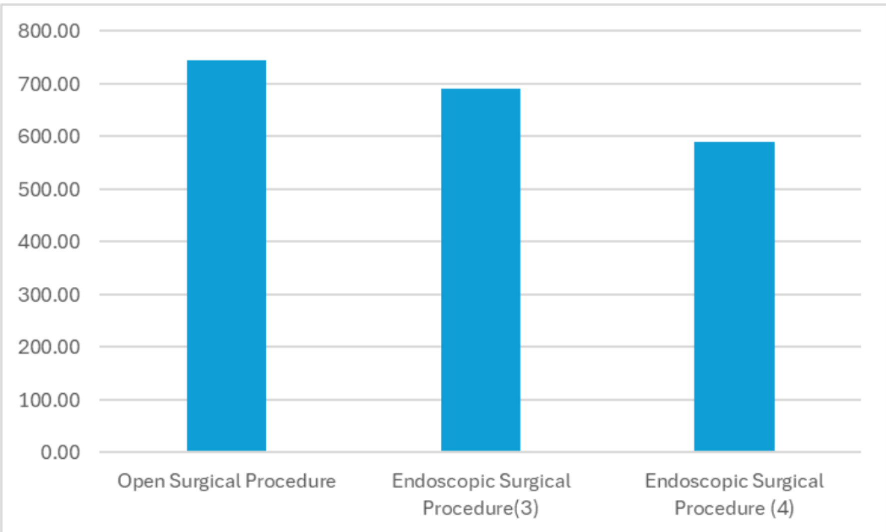
The reduction of approximately 100 kg CO_2-eq per surgery represents a significant opportunity for improving operating sustainability within the department. If scaled across the annual volume of procedures, this optimisation can translate into meaningful reductions in the environmental impact of lumbar herniation surgery at AUH. From a hospital management perspective, these results suggest that resource efficiency is not only a matter of procurement decisions, but also of how procedures are scheduled and executed. The possibility of increasing number of daily surgeries without significantly increasing surrounding hospital infrastructure or energy consumption proportionally, serves as a reduction opportunity for the lumbar spine procedures and possibly for the Department of Brain and Spine Surgery's total environmental impact.

Although the results show that with an increase from three to four endoscopic procedures per day the environmental impact per surgery is lower, the overall environmental impact for the department on a daily basis is expected to rise, due to the increased activity. The expectation is that an increase in lumbar disc herniation surgeries performed per day will not conclude that the surgeries will be executed faster and therefore conclude the same yearly demand for surgeries. There can occur a rebound effect, where more surgeries are scheduled due to this new capacity, and that the Department of Brain and Spine Surgery at AUH will therefore execute more lumbar disc herniation surgeries than before the implementation of three surgeries per day. Another scenario is that the

Department of Brain and Spine Surgery will take back the surgeries outsourced for private hospitals, and that they thereby will increase the yearly amount of surgeries, taking back the emissions that would otherwise lie as a responsibility on the private hospitals. Taking back outsourced surgeries will further release this cost category, giving the hospital this money back that can now be used for other expenditures, resulting in a new (unknown) activity. These are therefore important aspects to evaluate and assess before potentially implementing four endoscopic lumbar disc herniation surgeries per day. It can therefore be discussed if this is trade-off with a negative rebound effect when assessing the overall environmental impact of performing lumbar disc herniation procedures at AUH.

Another aspect to take into account when converting from three to four endoscopic surgeries per day, is how it will affect the anaesthesia process. Currently, no change is made in the calculation of the LCA, but if a shift is made from general to regional or local anaesthesia, this must be accounted for. According to Oettingen, it is only possible to convert to performing four surgeries a day, if anaesthesia is converted to regional or local anaesthesia (Appendix A). The expectation is that further reductions can be realistic, depending on the equipment and medical products/pharmaceuticals required for this.

Based on this LCA study, the overall results show that the endoscopic procedure has a lower environmental impact than the open procedure, but combining it with converting from three to four surgeries per day will conclude the overall lowest environmental impact, see Figure 9.1.



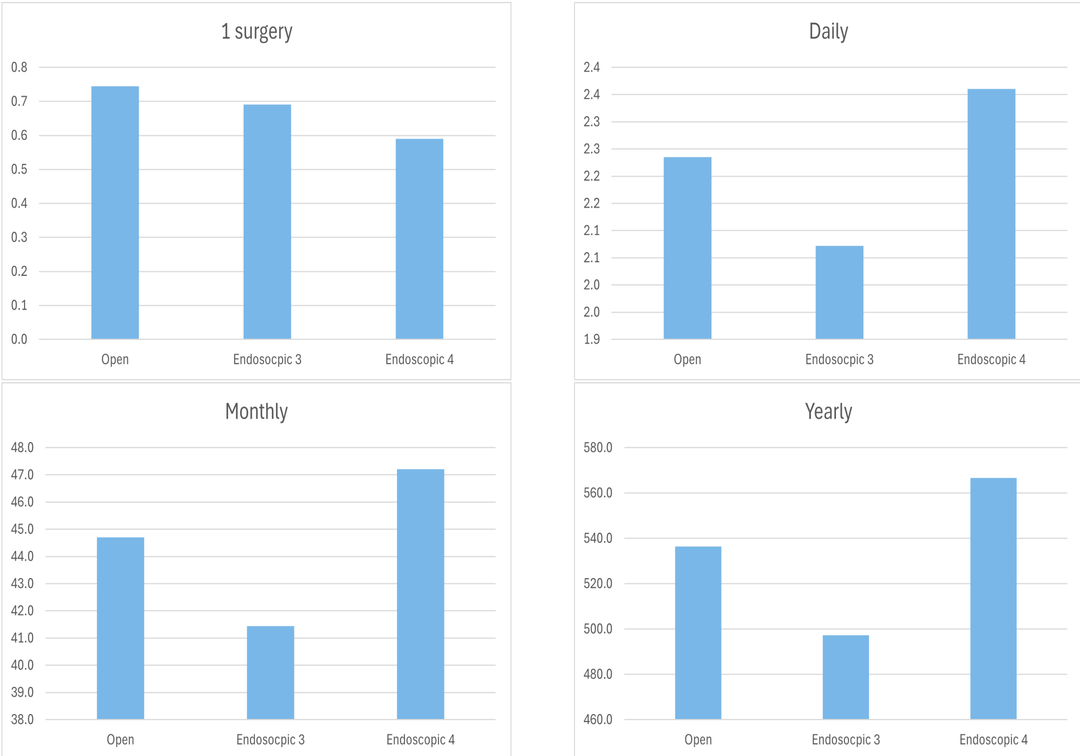
745 kg CO2-e	691 kg CO2-eq	590 kg CO2-eq

Figur 9.1. Overview of total results of the LCA study showing respectively open surgery, three daily endoscopic surgeries, and 4 daily endoscopic surgeries (own table).

To contextualise the environmental impact of converting from three open procedures per day to four endoscopic procedures per day, this is scaled to provide an overview of the environmental impact comparing the open procedure and the endoscopic procedures on a daily, monthly, and yearly basis, see Table 9.6. The table provides results based on the environmental impact per surgery, per day, per month, and per year, and this is shown graphically in Figure 9.2.

Table 9.6. Overview of the three scenarios for respectively open surgery, endoscopic surgery with three surgeries per day, and endoscopic surgeries with four surgeries per day. The results are provided in tonnes CO_2-eq (own table).

Emissions for	**Open procedure 3 sugeries**	**Endoscopic procedure 3 surgeries**	**Endoscopic procedure 4 surgeries**	**Unit**
1 surgery	0.7	0.7	0.6	tonnes CO_2-eq
Daily	2.2	2.1	2.4	tonnes CO_2-eq
Monthly	44.7	41.4	47.2	tonnes CO_2-eq
Yearly	536.5	497.3	566.6	tonnes CO_2-eq



Figur 9.2. Overview of the three scenarios scaled from per procedure to daily, monthly, and yearly total environmental impact in tonnes CO_2-eq (own tables).

Based on this LCA's results, open procedure with three surgeries per day results in a total daily impact of 2,235 kg CO_2-eq per day, endoscopic procedure with three surgeries per day results in 2,073 kg CO_2-eq per day, and endoscopic procedure with four surgeries per day results in 2,360 kg CO_2-eq per day.

Although the per procedure impact is lower for the endoscopic procedure, 590 kg CO_2-eq compared to the 745 kg CO_2-eq for the open procedure, the total daily emissions may increase if the department chooses to perform four endoscopic procedures per day instead of three open procedures. This is an example of how efficiency gained on procedure level can lead to increased activity at the system level, and thereby off-setting or even reversing the environmental benefits.

It should be noted, that a conversion from three to four endoscopic procedures would, according to Oettingen, require a shift in anaesthesia practice, as regional or local anaesthesia is required. Bases on literetaure findings in Chapter 7, it is assumed that a conversion from general to regional or local anaesthesia will have a positive influence on the overall environmental impact reduction of the treatment, as volatile agents, such as sevoflurane have a higher environmental impact compared to agents, such as propofol given intravenouses (Gasciauskaite et al., 2024). This leads to an expected overall lower environmental impact when looking at for example a yearly scenario. If this is decided, the implications on the overall environmental impact should be assessed and evaluated.

This scenario becomes relevant if the increased capacity is used to meet rising demand or to reduce outsourcing, as suggested by Oettingen (Appendix A). While this may be beneficial from a healthcare delivery and economic perspective, it also highlights the importance of considering system-wide consequences when evaluating sustainability interventions. Therefore, to fully evaluate the environmental impact of converting from three to four surgeries per day through the use of regional or local anaesthesia, a comprehensive assessment is required, accounting for the environmental effects of different anaesthetic practices.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Discussion 10

This chapter discusses the findings of the study in relation to answering the overall research question, accordance with findings from the literature search, and broader implications of a potential shift in surgical procedure. The purpose of the discussion is to interpret the results and explore them in a more practical context with the case. Key methodological and modelling choices, assumptions, and uncertainties are considered to provide a nuanced understanding of the study's outcomes. It is important to provide this nuanced reflection of the LCA studies, as the results alone do not underline the importance of the knowledge that cannot be quantified.

10.1 LCA Findings & Reduction Opportunities

The overall LCA results conclude that there is a lower total GHG emission when converting from open procedure with a total emission of 745 kg CO_2-eq to endoscopic procedure with a total of 691 kg CO_2-eq. This concludes a total saving of 7% of the total environmental impact. The reduction primarily reflects the shorter admission for the patient in hospital and lower energy consumption by medico-technical instruments during surgery.

The findings show robust results when put through a sensitivity analysis on relevant uncertainties. Further, the results are coherent with findings in relevant literature, analysed in Chapter 7, which specifically highlights how time in admission and optimising work-flows within the operating room can reduce environmental impacts. Studies assessing patient pathways across different procedures identify admission and operating room activities, such as electricity consumption and single use equipment, as the largest contributors to GHG emissions within the healthcare sector. For instance, studies on colorectal surgeries, acute heart failure, and coronary stenting have concluded a total environmental impact from 1.3 tonnes to more than 72 tonnes CO_2-eq per surgery, where duration of surgery and admission are key contributors (Bischofberger et al., 2023; Zhang et al., 2022; Sack et al., 2024).

The results shoved that admission account for 135.12 kg CO_2-eq for the open procedure and 67.56 kg CO_2-eq for the endoscopic procedure. The admission is calculated by using provided information on hospital costs in connection with an admission in the Ward of Brain and Spine Surgery provided by Oettingen. The numbers estimate cost and length associated with an admission for a disc herniation patient, one for open surgery and one for endoscopic surgery (Appendix A). The impacts are calculated by using EXIOBASE's process *"139 Health and social work"*, which represents a wide range of hospital activities. In contrast to this approach, Prasad et al. (2022) estimates the environmental impact of admissions by using more specific data from process data on consumption, gases, and waste treatment, and including more general IO data on food and cleaning services resulting in an overall impact of 38 kg CO_2-eq per patient. As these LCA studies are conducted with a different approach compared to this study, it makes it difficult to compare the overall results. However, the findings from the literature review provides a useful benchmark when assessing the overall conclusions of the findings in this study. The emissions related to admissions found in this study is supported by the literature review, as it falls within the estimated range of CO_2-eq in connection with patient admissions. This suggests, that the use of monetary units to calculate the environmental emissions in connection with admissions still results in a realistic result in the scenarios where physical data is either not available or too comprehensive to gather.

The environmental impact reductions and benefits of converting to endoscopic procedures is however not without trade-offs. The use of single use equipment has a higher environmental impact for the endoscopic procedure with an emission of 19.65 kg CO_2-eq compared to the open procedure with 12.24 kg CO_2-eq. This increase is due to the inclusion of additional single use equipment required for the endoscopic procedure. However, there is uncertainty regarding the precise quantity and frequency of single use equipment used in the endoscopic procedure. Due to lack of data from AaUH, it was not possible to fully map the actual consumption. This means that the environmental impact of single use equipment in the endoscopic procedure may be either over- or underestimated. A more accurate assessment could either shift the comparative results in either direction, depending on whether the actual use is higher or lower than assumed. This study could have taken pro active action and accounted for this through a sensitivity analysis. However, this would fail to capture the nuances that could be present in material types of the single use equipment, which would have to be based on an assumed general material type in order to assess the impact. If further single use equipment is used for the endoscopic procedure, this should be accounted for before implementing the new practice. An increase from 12.24 kg CO_2-eq to 19.65 kg CO_2-eq may be significant looking at it isolated, but in the total emission of a surgery, this is a rather insignificant difference at approximately 1%.

Another consideration relates to the potential for further environmental reductions through increased surgeries. As explored in the second analysis in Chapter 9, the endoscopic procedure allows for the possibility of performing four surgeries per day instead of three, due to its shorter surgery and admission duration. When calculating the environmental impact per procedure in this scenario, the total emission per endoscopic procedure decreases from 690.70 kg CO_2-eq to 590.18 kg CO_2-eq. This reduction is primarily attributed to a more efficient use of overall daily functions, such as use of energy sources as lighting, ventilation, and heating, which remain active throughout the day regardless of the number of surgeries performed.

10.2 Socio-economic Considerations

Beyond the environmental impacts, the choice between open and endoscopic procedure for lumbar disc herniation surgeries also entails socio-economic considerations. These includes patient quality, healthcare efficiency, economic trade-offs, and resource utilisation.

From the patient's point of view, the endoscopic procedure offers several advantages. Due to its less invasive nature, patients typically experience less postoperative pain, shorter admission and faster recovery. As noted by Oettingen and Bjarkam, the average sick leave following the open procedure is approximately four to six weeks, whereas patients undergoing the endoscopic procedure may return to work within two to three weeks (Appendix A and C. This reduction in recovery time not only improve the patient's quality of life but also has a broader economic influence by reducing socio-economic losses in connection with a surgery of a patient.

For the healthcare system, the shorter admission associated with endoscopic procedures reduce the burden on hospital beds and staff. This reduction can lighten pressure on departments with limited capacity. Furthermore, the potential to increase the number of surgeries from three to four procedures per day, as analysed in Chapter 9, enables more efficient use of operating rooms and staff resources. This increased capacity can help reduce waiting time for patients and outsourcing surgeries to private hospitals, which is currently done to meet the demand for lumbar disc herniation surgeries (Appendix A.

While endoscopic procedures require initial investment in specialised equipment and training of surgeons, this cost may be off-set by savings in other areas. These include reduced admission expenses, lower anaesthesia requirements, and decreased outsourcing expenses. As outlined by Oettingen, the cost per surgery is initially higher for endoscopic procedures, when performed under general anaesthesia. However, Oettingen has expressed that the Department of Brain and Spine Surgery want to explore the possibility of performing the endoscopic procedure under regional or local anaesthesia in the future, with the aim of further reducing cost and increasing surgical capacity.

A study by Gasciauskaite et al. (2024) highlights the environmental impacts of different anaesthesia methods. In particular, the distinction between volatile and intravenous anaesthesia is highlighted. Volatile anaesthetic agents, such as sevoflurane, are potent GHG that are exhaled by patient and released directly into the atmosphere, where they contribute to global warming. In contrast, intravenous anaesthesia, such as propofol has a lower environmental impact. Intervenors agents are metabolised within the body and do not escape into the atmosphere. Additionally their impact per g used is generally lower, and they do not act as green house gases (Khalil et al., 2024). This indicated that intravenous anaesthesia is a more sustainable option than volatile. This distinction is also relevant in the context of local anaesthesia, as local anaesthesia often does not involve the use of volatile gases. Instead, it typically relies on intravenous sedation or regional nerve blocks (Ravn and Larsen, 2022). As such local or regional anaesthesia represents not only a potential economic advantage but also a potential environmental benefit.

It is however important to note, that this perspective of converting to regional or local anaesthesia is not universally shared. Bjarkam raises concerns about the use of regional and local anaesthesia in this context, pointing out that it may lead to discomfort for both patient and surgeon. Due to this knowledge, general anaesthesia remains the standard practice at AaUH (Appendix C).

An article by Gadjradj et al. (2022), supports the potential socio-economic benefits of endoscopic procedures. The article investigates the cost-effectiveness of percutaneous transforaminal endoscopic discectomy (PTED) compared with open micro discectomy among patients with sciatica, not specifically lumbar disc herniation as examined in this study. The article found, that although the surgical costs were higher for the endoscopic surgery, the total socio-economic cost was lower due to shorter sick leave, reduced need for patient care, and lower cost of pharmaceuticals and follow-up consultations (Gadjradj et al., 2022). The article indicted that PTED is more effective for patients and less costly for society when compared to open surgery. However, it is important to note that the study only included patients eligible for both procedures, and the findings cannot be directly generalised to all patients with lumbar disc herniation. Nevertheless, it is argued that achieving cost-effectiveness within a selected patient group can still contribute to a more efficient healthcare practice overall (Gadjradj et al., 2022).

This is further supported by a simple estimation of the social cost of sick leave in a Danish context. Based on average monthly salaries and public subsidies, the cost of 35 days of sick leave, the typical recovery time for the open procedure, is approximately 80,063 DKK based on average salary, while 24.5 days, the typical sick leave for patients treated with endoscopic procedure, concludes 54,044 DKK. This results in a difference of 24,019 DKK per patient, representing the socio-economic savings by converting from open procedure to endoscopic procedures (Danmarks Statistik, 2025). These calculations are based on average working hours and income level. While these numbers do not succeed in capturing all aspects of patient experienced quality such as quality of life through the treatment, this provides as a tangible estimate of the socio-economic impact of changing treatment practice and thereby reduce recovery time.

Despite its benefits, the endoscopic procedure is not suitable for all patients. According to Bjarkam, only approximately 20% of patients meet the anatomical criteria for the approach. The selection of patients for endoscopic procedure is therefore based physical suitability. It should be noted, that the patient population affected by lumbar disc herniation is diverse, but a significant proportion are of working age. There can be a bias in the patient group related to the occupational exposure, as physically demeaning jobs may increase the risk of disc herniation and influence the ability to return back to work (Appendix C.)

10.3 Methodological Considerations

Throughout this study there has been uncertainties that have influenced the modelling of the LCA and interpretation of the results. These uncertainties are not only methodological, but also reflect the complexity of healthcare settings and the variability of surgical procedures. An uncertainty that has influenced the study lies in the variability of patient pathways. Although the functional unit is defined to represent an average patient undergoing surgical treatment for lumbar disc herniation, no patients are identical. Differences in physical conditions can influence the course of treatment, recovery time, and ultimately the environmental impact.

Assumptions about the lifespan of reusable instruments also contribute to uncertainties. Reusable instruments were modelled with 1,000 uses over their lifespan, based on expert inputs. However, as analysed in Section 8.3.2, deviations from this assumption due to damage or loss could affect the environmental impact per procedure. Although the sensitivity analysis showed the model to be relatively robust to reuse frequency, the assumption remains a simplification of real-world practices. Furthermore, the exclusion of post discharge activities such as rehabilitation introduces limitations. Due to data limitations, these stages were excluded from the system boundary. This likely results in an underestimation of the environmental impact for both the open procedure and endoscopic procedure, when considering the complete patient pathway.

Finally, the implementation phase of endoscopic procedures introduces temporal uncertainty. As noted by both Oettingen and Bjarkam, the adoption of this procedure involves a learning curve, during which surgery time may take longer, more X-rays pictures might be taken, and complication rates can be enhanced. These transitional dynamics are not accounted for in the LCA (Appendix A and C).

10.4 Rebound Effects

In Chapter 9 it is mentioned that introducing four endoscopic procedures per day can lead to unforeseen rebound effects from the increased hospital activity and released economic resources. This increased activity can reduce the environmental impact per patient, particularly through more efficient use of electricity, district heating and staff resources.

Another important consideration is expressed by Bjarkam, who mentions scenarios where a decided endoscopic procedure may turn over to proceed as an open procedure, if complications arise in the operating room (Appendix C). This entails that instruments and equipment for both procedures are taken into use in the operating room, leading to an overall higher environmental impact. This is not accounted for in the LCA, as it is complex to model due to its high uncertainty of frequency and is highly dependent on the condition of the specific patient in question.

These rebound effects highlight the importance of adopting a system perspective when evaluating sustainability interventions. Their broader implications must be evaluated to avoid unintended increases in total environmental impact.

10.5 Reflections

Several methodological and practical choices could have been adjusted to strengthen the robustness and completeness of this LCA. While the study provides a detailed and comparative LCA of the two surgical procedures, certain limitations related to data availability and scope have influenced the outcome.

One of the opportunities for improvement would have been to conduct a site visit to the hospital ward. As explained in Section 8.2, admissions were modelled using monetary data, which, although useful, only provides an aggregated estimate of resource use. A visit to the ward could have included more precise quantification of physical flows such as pharmaceuticals, food, and equipment consumption. This would have allowed for a more nuanced insight to the admission stage and potentially revealed differences between the two procedures.

Another area that could have been explored further is the environmental impact of anaesthesia. In the current model, general anaesthesia is assumed for both procedures, which ensures consistency in the comparative LCA. However, as noted by Oettingen, the implementation of local and regional anaesthesia is being considered for the endoscopic procedure in connection with the ambition to convert from three to four procedures per day (Appendix A). Including local anaesthesia as a scenario in the LCA would have allowed for a more precise estimate of the environmental impact associated with the shift to four daily procedures analysed in Chapter 9. Modelling regional or local anaesthesia would have required observation, as well as detailed data collection of the specific equipment, medico-technical instruments and pharmaceuticals used. Since neither AUH or AaUH performs lumbar disc herniation surgeries under local anaesthesia, such scenario would necessarily have been based on assumptions, expert inputs, or other studies, rather than primary data.

Additionally, the study could have benefitted from a more detailed mapping of the rehabilitation phase. although rehabilitation is excluded from the system boundary due to data limitations, it is likely to differ between the two procedures, as suggested by both Oettingen and Bjarkam (Appendix A and C). Including municipal rehabilitation services and physiotherapy sessions could have provided a more holistic assessment of the pathway.

A further improvement could have been the implementation of a more dynamic or scenario-based modelling approach. For example, modelling different adoption scenarios, such as partial versus full implementation of the endoscopic procedure, or the introduction of regional or local anaesthesia, could have allowed for a more explicit treatment of rebound effects, which are currently discussed qualitatively but not modelled quantitatively. As an example this could have been done by testing Oettingen's assumption of converting 20% of the total lumbar disc herniation surgeries into endoscopic procedure and measured the effect.

10.6 Transparency and Data Limitations

One of the key principles in LCA is transparency, both in terms of data sources and modelling assumptions. While this study has aimed to maintain a high level of transparency throughout, several limitations related to data availability and confidentiality have influenced the modelling process and the reproducibility of the results.

One of the primary challenges is the limited access to physical data for certain product categories, particularly in the case of the endoscopic procedure. At AUH, the SupplyAID system enabled detailed tracking of single use equipment used in the open procedure, resulting in the possibility in obtaining the specific product weight, material composition and frequency of use. However, a similar system was not available at AaUH, where the endoscopic procedure was observed and physical data was challenging to obtain. As a result, the modelling of single use equipment for the endoscopic procedure relied on a combination of proxy data from the open procedure, supplier inputs, and observational estimates. While these sources provided a reasonable approximation, they introduce a degree of uncertainty and reduce the reproducibility of the results. In addition, several product prices and procurement data were subjected to confidentiality agreements. This means that monetary values are aggregated in a way, that they cannot be traced back to specific products or services. Although this approach preserves the integrity of the analysis and respect data confidentiality agreements, it limits the ability of other researchers to replicate the study in full detail.

These limitations highlights the importance of using physical data wherever possible in future studies. Physical data, such as weight and material type, allow for more precise environmental impact and reduces reliance in assumptions or monetary data, which can vary significantly depending on market conditions and supplier contracts.

The products available physically have however been calculated by measuring the specific weight and determining the material composition by using a plastic scanner. The data on the available products are therefore determined and included based on a relatively high quality data collection.

10.7 Perspectives

The findings of this study have several implications for both clinical practice and strategic decision making in the healthcare sector. By quantifying and comparing the environmental impact of open and endoscopic procedures for lumbar disc herniation, the study contributes to more sustainable surgical practices. However, the results must be interpreted in light of a broader clinical, organisational and methodological context. The findings suggest that a shift toward endoscopic procedures can contribute to the environmental goals outlined in the Danish Regions' climate strategy, presented in Section 1, particularly in relation to reducing emissions from procurement and energy use.

However, the potential for rebound effects must be carefully considered. If the increased efficiency of endoscopic procedures leads to a higher total number of performed surgeries, the overall environmental impact of the department may increase, despite lower emissions per procedure. This highlights the need for system-level thinking when implementing sustainability initiatives in the healthcare sector. Environmental gains at the procedure level must be balanced against system-level consequences, including changes in patient flow, resource allocation and clinical practice.

At the same time, it is important to acknowledge that environmental sustainability is only one of several priorities in healthcare decision making, and often not the most prioritised. In contrast to private organisations that may prioritise profit or environmental branding, hospitals operate within a framework where patients' experienced quality, clinical effectiveness, and economic feasibility are crucial. When human health is at stake, environmental considerations may be deprioritised if they are perceived to compromise patient quality and staility within hospital infrastructure.

As stated, the pressuring global challenge in climate change is continuing to affect overall global health, and therefore an aspect that should be taken into account when improving or assessing healthcare and treatment solutions. It must be integrated into a broader evaluation framework that also includes patient perceived quality, clinical outcomes and cost-efficiency. In Denmark, this is reflected in the national quality model, where patient perceived quality is assessed alongside dimensions such as safety, coherence and resource use (Danske Regioner, 2025b). As highlighted by Arnadottir et al. (2023), there is a growing interest in embedding sustainability into healthcare practice as a complementary one that supports long-term resilience and responsible resource management.

11 Conclusion

This chapter will answer the overall research question, represented here again to clarify what is answered:

How can the environmental impact of a lumbar disc herniation surgical procedure be assessed and reduced to support sustainable healthcare?

This study set out to assess and compare the environmental impact of two surgical procedures for treating lumnbar disc herniation; open and endoscopic procedure, using LCA. Through collaboration with healthcare experts, observation of procedures, and a comprehensive data collection of the patient pathway in connection a lumbar disc herniation patient, this study has provided valuable insights into how surgical practices and their environmental impacts can be assessed and reduced.

The results conclude a total of 745 kg CO_2-eq for open procedures and 691 kg CO_2-eq for endoscopic procedures. This concludes an overall potential of reducing the environmental impacts in connection with lumbar disc herniation patients by approximately 7%. A further reduction can be found in converting from general to regional or local anaesthesia, and by this introducing the possibility of conducting four instead of three endoscopic procedures per day at the Department of Brain and Spine Surgery at AUH. This concludes an overall saving of approximately 21% for the conversion from three open surgical procedures to four endoscopic surgial procedures per day.

The concluded reduction by converting from open procedure to endoscopic procedure is primarily influenced by the reduced admission duration, and use of medico-technical instruments. The reduction found in converting from three to four endoscopic procedures per day is influenced by the daily running consumption of electricity and district heating, which is not assessed to be significantly changed, and the available staff in the department. As the endoscopic procedure introduces the possibility of including an extra surgery per day, this highlights the importance of including systemic factors where procedures can be optimised and benefit the wider system. However, the inclusion of a fourth procedure per day requires a shift in anaesthesia practice, as this must be converted to regional or local anaesthesia instead of general. If such change is durable, further GHG emission reductions are expected. However, this study also highlighted the risk of rebound effects, where increased surgical capacity could lead to higher overall activity and thereby increased total emissions.

The study highlights the complexity of quantifying environmental impacts, especially when conducting an LCA within healthcare settings. The overall results can be compromised by a range of influencing factors. However, a sensitivity analysis of the results indicate that the findings are robust to relevant changes within the system. Moreover, communication of possible sensitivities in this study can beneficially provide knowledge to healthcare practitioners within the Department of Brain and Spine Surgery, in order to gain awareness of which activities have a relative high or low impact in connection with the environmental impacts related to a lumbar disc herniation surgery.

Importantly, the study highlights that LCA modelling involves subjective choices that influence outcomes. Epistemological and ontological considerations, such as the use of consequential modelling, choice of system boundaries, and hybrid data, plays a key role in shaping the results. The study also reflects on the tension between the "system world" of LCA models and the "life world" of clinical realities, underscoring the need for dialogue and mutual understanding between environmental experts and healthcare professionals.

In conclusion, this thesis contributes to the growing field of sustainability in healthcare by providing a detailed case study and methodological reflections. It shows how LCA can serve as a decision support tool, not only for assessing current practices but also for guiding future transitions toward more sustainable healthcare systems.


PHILIPS
IntelliVue
STANDBY
PHILIPS
MX550
Dräger
Standby
Dräger
HUSK UDSUGNING
Perseus A500

References

Aalborg University Library. SpringerLink., 1832.

Aalborg University Library. Web of Science Core Collection., 1899.

Aalborg University Library. Scopus., 1996.

Alcimed. Patient Pathway: Streamline patient care, 2025. URL https://www.alcimed.com/en/expertise/patient-pathway/.

Amgros. Forside - Amgros, 2025. URL https://amgros.dk/home/.

Asthildur Arnadottir, Nanna Holt Jessen, Martin Schønemann-lund, and Torsten Risør. Bæredygtig sundhedsforskning, October 2023. URL https://ugeskriftet.dk/videnskab/baeredygtig-sundhedsforskning.

AU Libery. Reviews, January 2025. URL https://library.au.dk/forskere/reviews.

Roy F. Baumeister and Mark R. Leary. Writting Narrative literature reviews. *Review of General Psychology*, 1.(3):311–320, September 1997. URL https://psychology.yale.edu/sites/default/files/baumeister-leary.pdf.

Bilbasen Blog. Ny vs brugt bil: Hvad kan bedst betale sig?, April 2024. URL https://blog.bilbasen.dk/ny-vs-brugt-bil-hvad-kan-bedst-betale-sig-455888/.

Stephan Bischofberger, Fiona Adshead, Keith Moore, Mesut Kocaman, Gianluca Casali, Cindy Tong, Sanjoy Roy, Michael Collins, and Walter Brunner. Assessing the environmental impact of an anastomotic leak care pathway. *Surgery Open Science*, 14: 81–86, August 2023. ISSN 2589-8450. doi: 10.1016/j.sopen.2023.07.001. URL https://www.sciencedirect.com/science/article/pii/S2589845023000362.

Center for Bæredygtige Hospitaler. Bæredygtige Operationer, 2025. URL https://www.cfbh.rm.dk/sadan-arbejder-vi/projekter-i-centeret/baredygtige-operationer/.

Danmarks Statistik. Forbrugerprisindeks, December 2023. URL https://www.dst.dk/da/Statistik/emner/oekonomi/prisindeks/forbrugerprisindeks.

Danmarks Statistik. Gennemsnitsdanskeren, 2025. URL https://www.dst.dk/da/Statistik/laer-om-statistik/gennemsnitsdanskeren.

Danske Regioner. *En fællesregional strategi for Grønne hospitaler*. Danske Regioner, 2023. ISBN 978-87-7723-121-6.

Danske Regioner. Om de fem regioner, July 2025a. URL https://www.regioner.dk/om-os/om-de-fem-regioner/.

Danske Regioner. Patientoplevet kvalitet, 2025b. URL https://www.regioner.dk/sundhed/kvalitet-og-styring/patientoplevet-kvalitet/.

Digitalisering og It, Region Midtjylland. Annoncering af Supply aid, May 2024. URL `https://www.linkedin.com/posts/digitalisering-og-it-region-midtjylland_dias-forsyningogservice-supplyaid-activity-7196048567440969728-ga4-/?originalSubdomain=dk`.

Kajene Elankanathan. Visit at sterile central at AUH, April 2025.

Jonas Lassen Eliassen and Margarida Varandas. Metodedokument til materialebibliotek of respektive emissionsintensiteter (DRAFT). Technical report, 2.-0 LCA, January 2024.

Amin Esmaeili, Charles McGuire, Michael Overcash, Kamran Ali, Seyed Soltani, and Janet Twomey. Environmental impact reduction as a new dimension for quality measurement of healthcare services. *International Journal of Health Care Quality Assurance*, 31(8):910–922, October 2018. ISSN 0952-6862. doi: 10.1108/IJHCQA-10-2016-0153.

European Union. Regulation (EU) 2021/1119 of the European Parliament and of the Council of 30 June 2021 establishing the framework for achieving climate neutrality and amending Regulations (EC) No 401/2009 and (EU) 2018/1999 ('European Climate Law'), June 2021. URL `http://data.europa.eu/eli/reg/2021/1119/oj/eng`. Legislative Body: CONSIL, EP.

Eurpean Union. Global climate action - European Commission, July 2025. URL `https://climate.ec.europa.eu/eu-action/international-action-climate-change/global-climate-action_en`.

Pravesh Shankar Gadjradj, Hana M Broulikova, Johanna M Van Dongen, Sidney M Rubinstein, Paul R Depauw, Carmen Vleggeert, Ankie Seiger, Wilco C Peul, Job L Van Susante, Maurits W Van Tulder, and Biswadjiet S Harhangi. Cost-effectiveness of full endoscopic versus open discectomy for sciatica. *British Journal of Sports Medicine*, 56(18):1018–1025, September 2022. ISSN 0306-3674, 1473-0480. doi: 10.1136/bjsports-2021-104808. URL `https://bjsm.bmj.com/lookup/doi/10.1136/bjsports-2021-104808`. Publisher: BMJ.

Greta Gasciauskaite, Justyna Lunkiewicz, Michael Tucci, Corinna Von Deschwanden, Christoph B. Nöthiger, Donat R. Spahn, and David W. Tscholl. Environmental and economic impact of sustainable anaesthesia interventions: a single-centre retrospective observational study. *British Journal of Anaesthesia*, 133(6):1449–1458, December 2024. ISSN 0007-0912. doi: 10.1016/j.bja.2023.11.049. URL `https://www.sciencedirect.com/science/article/pii/S000709122300692X`.

Green House Gas Protocol. IPCC Global Warming Potential Values. Technical Report 0.2, Green House Gas protocol, August 2024. URL `https://ghgprotocol.org/sites/default/files/2024-08/Global-Warming-Potential-Values%20%28August%202024%29.pdf`.

International Standard. ISO 14040:2006, Environmental management - Life cycle assessment - Principles and framework, January 2006.

Liselotte Jensen. Denmark's climate action strategy | Think Tank | European Parliament, July 2025. URL https://www.europarl.europa.eu/thinktank/en/document/EPRS_BRI(2024)767173.

Vanesa Jiménez-Lacarra, Eduardo Martínez-Cámara, Juan Carlos Sáenz-Diez Muro, Emilio Jiménez-Macías, and Julio Blanco-Fernández. Environmental Benefits of Reducing Patient Mobility and Hospitalization. *Sustainability*, 16(24):11073, January 2024. ISSN 2071-1050. doi: 10.3390/su162411073. URL https://www.mdpi.com/2071-1050/16/24/11073. Number: 24 Publisher: Multidisciplinary Digital Publishing Institute.

Ramy Khalil, Zhengmin Ma, David Lubarsky, Ke Peng, Fuhai Ji, and Hong Liu. The environmental effects of anesthetic agents and anesthesia practices. *Journal of Anesthesia and Translational Medicine*, 3(4):166–170, December 2024. ISSN 2957-3912. doi: 10.1016/j.jatmed.2024.10.004. URL https://www.sciencedirect.com/science/article/pii/S2957391224000834.

Robert V. Labaree. Research Guides: Organizing Your Social Sciences Research Paper: 5. The Literature Review, 2025. URL https://libguides.usc.edu/writingguide/literaturereview.

Mads Lænsø Madsen. Meeting about medico-technical intruments, March 2025.

Jan Maintz, Thomas Svane Christensen, Anders Ølsgaard Larsen, Mads Rangvid, and Torben Benoni. De humanistiske videnskaber, February 2012. URL https://vidensmoenstre.systime.dk/?id=240&L=1.

H. Scott Matthews, Chris T. Hendrickson, and Deanna H. Matthews. *Life Cycle Assessment: Quantitative Approaches for Decisions That Matter*. Carnegie Mellon University, 2014. URL https://cmu.app.box.com/s/5mnzyq1y3gcyjrveubf4/file/23378453164.

Scott McAlister, Forbes McGain, Matilde Petersen, David Story, Kate Charlesworth, Glenn Ison, and Alexandra Barratt. The carbon footprint of hospital diagnostic imaging in Australia. *The Lancet Regional Health. Western Pacific*, 24:100459, July 2022. ISSN 2666-6065. doi: 10.1016/j.lanwpc.2022.100459.

Microsoft 365. Copilot til alle, 2025. URL https://www.microsoft.com/da-dk/microsoft-365/copilot/copilot-for-work.

Ministry of Environment and Food of Denmark. Arla Foods Environmental Profit and Loss Accounting 2014. Technical Report 1860, Ministry of Environment and Food of Denmark, 2016. URL https://lca-net.com/files/978-87-93435-75-9.pdf.

Susanne Mott. Dansk Rygdatabase (DaRD). *Årsrapport*, 2023:9, 2024.

NotebookLM. Google NotebookLM | Note Taking & Research Assistant Powered by AI, 2025. URL https://notebooklm.google/.

OpenAI. Introducing ChatGPT, March 2022. URL https://openai.com/index/chatgpt/.

Purnima Aishwarya Prasad, Dhruvi Joshi, Jennifer Lighter, Jenna Agins, Robin Allen, Michael Collins, Foohel Pena, Joan Velletri, and Cassandra Thiel. Environmental footprint of regular and intensive inpatient care in a large US hospital. *The International Journal of Life Cycle Assessment*, 27(1):38–49, January 2022. ISSN 1614-7502. doi: 10.1007/s11367-021-01998-8. URL `https://doi.org/10.1007/s11367-021-01998-8`.

Hanne Berg Ravn and Erling Peter Larsen. Anæstesi, lokal og regional - Lægehåndbogen på sundhed.dk, September 2022. URL `https://www.sundhed.dk/sundhedsfaglig/laegehaandbogen/kirurgi/tilstande-og-sygdomme/anaestesi/anaestesi-lokal-og-regional/`.

Fabian Sack, Amanda Irwin, Raymond van der Zalm, Lorraine Ho, Danielle J. Celermajer, and David S. Celermajer. Healthcare-related carbon footprinting-lower impact of a coronary stenting compared to a coronary surgery pathway. *Frontiers in Public Health*, 12:1386826, 2024. ISSN 2296-2565. doi: 10.3389/fpubh.2024.1386826.

Tejas S. Sathe, Thomas A. Sorrentino, Kaiyi Wang, Ava Yap, Jaeyun Jane Wang, Madeline Matthys, Raymond Yin, Adnan Alseidi, Hanmin Lee, and Seema Gandhi. Instrument and Supply Variability: An Opportunity to Reduce the Carbon Footprint of the Operating Room. *The Journal of Surgical Research*, 295:732–739, March 2024. ISSN 1095-8673. doi: 10.1016/j.jss.2023.11.004.

Anna Savio, Beatrice Marchi, Andrea Roletto, Giuseppe Milano, and Simone Zanoni. Sustainable Operating Rooms: A Comprehensive Framework for Environmental Impact Analysis. *Environmental and Climate Technologies*, 28(1), December 2024. doi: 10.2478/rtuect-2024-0064. URL `https://sciendo.com/article/10.2478/rtuect-2024-0064`.

J. Schmidt and S. Merciai. Technical report: GHG emissions from Danish consumption 2016 - causal link between consumption and GHG emissions. Technical report, 2.-0 LCA, 2023. URL `https://concito.dk/files/media/document/Bilagsrapport%201_GHG%20emissions%20from%20Danish%20consumption%202016.pdf`.

Nathalia Silva de Souza Lima Cano, Ian D. Engler, Rezvan Mohammadiziazi, Federica Geremicca, Dylan Lawson, Nicholas Drain, Volker Musahl, Bryson P. Lesniak, and Melissa M. Bilec. How Can the Environmental Impact of Orthopaedic Surgery Be Measured and Reduced? Using Anterior Cruciate Ligament Reconstruction as a Test Case. *Clinical Orthopaedics and Related Research*, 483(1):7–19, January 2025. ISSN 1528-1132. doi: 10.1097/CORR.0000000000003242.

Guido Sonnemann, Bruce Vigon, Sonia Valdivia, and Mirelle Rack. Global Guidance Principles for Life Cycle Assessment Databases - A Basis for Greener Processes and Products. Guide, UNEP/SETAC Life Cycle initative, 2011. URL `https://www.lifecycleinitiative.org/wp-content/uploads/2012/12/2011%20-%20Global%20Guidance%20Principles.pdf`.

Cassandra L. Thiel, Matthew Eckelman, Richard Guido, Matthew Huddleston, Amy E. Landis, Jodi Sherman, Scott O. Shrake, Noe Copley-Woods, and Melissa M. Bilec. Environmental Impacts of Surgical Procedures: Life Cycle Assessment of Hysterectomy in the United States. *Environmental Science & Technology*, 49(3):1779–1786, February 2015. ISSN 0013-936X. doi: 10.1021/es504719g. URL https://doi.org/10.1021/es504719g. Publisher: American Chemical Society.

Sven Thorgaard. Habermas' systemverden og livsverden, June 2024. URL https://www.kristeligt-dagblad.dk/religion/habermas-systemverden-og-livsverden.

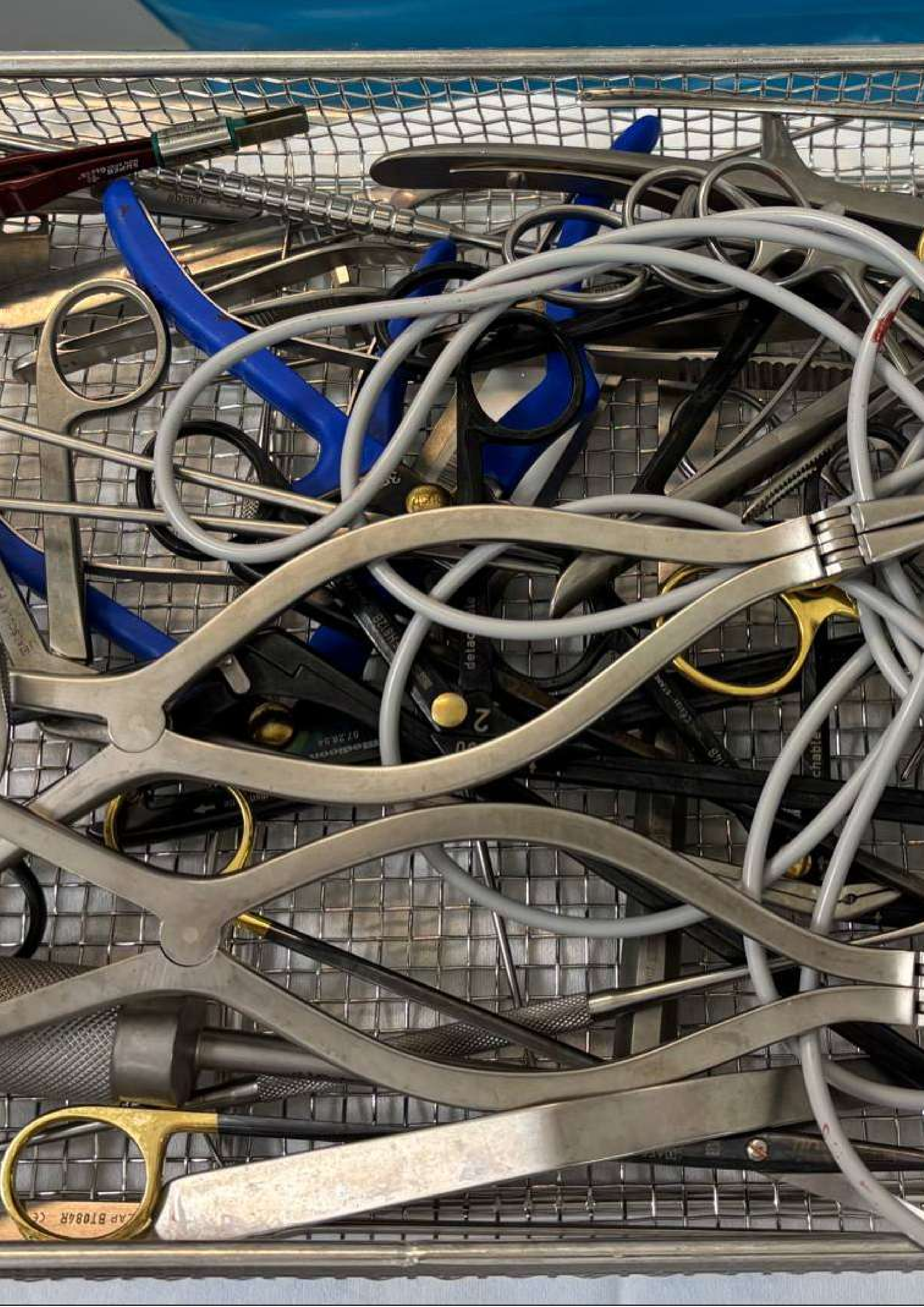
Thorsten Thurén. *Videnskabsteori for begyndere*. Hans Reitzels Forlag, 3 edition, 2021. ISBN 978-87-02-32692-5.

United Nations Global Marketplace. What are UNSPSC codes?, May 2024. URL https://help.ungm.org/hc/en-us/articles/360012816160-What-are-UNSPSC-codes.

Bo Weidema. Market information in life cycle assessment. Environmental project 863 2003, Danish Environmental Protection Agency - Danish Ministry of the Environment, 2003. URL https://lca-net.com/files/Market-information-in-life-cycle-assessment.pdf.

World Health Organisation. Climate change, July 2025. URL https://www.who.int/health-topics/climate-change.

Xiange Zhang, Klaus Albrecht, Stefan Herget-Rosenthal, and Wolf H. Rogowski. Carbon footprinting for hospital care pathways based on routine diagnosis-related group (DRG) accounting data in Germany: An application to acute decompensated heart failure. *Journal of Industrial Ecology*, 26(4):1528 – 1542, 2022. doi: 10.1111/jiec.13294. URL https://www.scopus.com/inward/record.uri?eid=2-s2.0-85135149652&doi=10.1111%2fjiec.13294&partnerID=40&md5=647f73b2c741299407815d25de4d52f5. Type: Article.



Mail from Oettingen A

This appendix includes the initial mail correspondence fro Gorm von Oettingen, Head of the Department of Brain and Spine Surgery at AUH. The email outlines the background for the case study, including the rationale for exploring a shift from open procedure to endoscopic procedure, expected benefits and challenges, and preliminary cost estimates. The content has served as foundation fro case formulation and modelling throughout the study. This text has been translated from Danish to English using Copilot.

Mail from Oettingen
The department Brain and Spine Surgery performed a total of 780 spinal disease operations in 2023, of which 510 were lumbar (lower back) surgeries for degenerative conditions (herniated discs and stenosis). Activity is expected to increase further in 2024, partly due to the repatriation of patients from private healthcare providers.

The average hospital stay after spinal surgery is relatively short, averaging around 40 hours.

On average, patients are unable to work for about one month following surgery.

Restructuring – Advantages and Disadvantages
The department initially aims to convert approximately 20 %, or just approximately 100, of the total lumbar spine surgeries to endoscopic methods, as this offers several benefits:

- Minimally invasive – reduced surgical trauma
- Lower infection rates
- Less postoperative pain
- Shorter hospital stays and faster rehabilitation (return to work reduced from 1 month to 7–14 days)
- Possibility of using alternative types of anaesthesia – eventually also local anaesthesia
- Reduced need for stabilizing fusion surgery

Specifically, the restructuring will include surgeries with the procedure codes "KABC16" *"Microsurgical removal of lumbar disc herniation"* and "KABC26" *"Open surgery for lumbar disc herniation"*.

Conversion to endoscopic methods is relevant for patients with low ASA scores/low comorbidity, or at the other end of the spectrum, patients who cannot tolerate general anaesthesia and therefore can only be treated under local anaesthesia.

For endoscopic surgery, the procedure code "KABC07" *"Percutaneous endoscopic removal of lumbar disc herniation"* will be used.

There are some disadvantages during the initial implementation phase of the new technique, including:

- Higher recurrence/reoperation rate (experiences from Aalborg show 18 %)
- Longer procedure times due to new equipment and workflow changes
- Experience with selecting suitable patients will only become clearer after the first 20–50 cases

Development Perspective
The endoscopic technique is already in use at Aalborg University Hospital, where more than 100 procedures have been performed so far. It is thus a technique gaining traction at all university hospitals and will become a natural part of professional development at university hospitals.

The transition to endoscopic techniques also means that, for properly selected patients, it will be possible to shift surgical treatment of lumbar disc herniation under general anaesthesia and inpatient care to same-day surgery performed under local anaesthesia.

This will reduce costs for anaesthesia and care, and by switching to local anaesthesia, the number of surgeries per operating day can increase from three to four.

Implementation:
Adopting the new technique requires a one-time investment in new equipment that must be integrated with existing systems. With procurement, the first lumbar endoscopic surgeries at AUH can be performed in Q3–Q4 2024 – under the guidance of an external surgeon. From Q4, fixed weekly surgery dates can be established to continue implementing the method. The department expects to perform 100 surgeries in 2025, divided between two surgeons.

Economy and Business Case
Implementing the endoscopic technique under general anaesthesia will initially increase the cost per surgery from DKK 15,689 to DKK 19,350 – an increase of DKK 3,661. This increase is primarily due to higher costs for instruments used in endoscopic surgery and depreciation of the purchased equipment. Conversely, ward costs will decrease as the length of stay is expected to be halved.

However, the additional cost of DKK 3,661 per surgery only applies when the endoscopic technique is performed under general anaesthesia. When switching to local anesthesia and eventually performing four surgeries per day instead of three, the restructuring will be cost-neutral.

The new technique also offers several health-economic benefits, including shorter hospital stays, fewer complications, faster recovery, and quicker return to work.

From a regional cooperation perspective, the expectation is that the new technique will reduce the number of Central Denmark Region residents seeking treatment outside the region.

Table A1. Cost estimations from Oettingen

Expenses per surgery/patient				
	Open procedure 3 OP per day General anaesthesia	**Endsoscopic procedure 3 OP per day General anesthesia**	**Endsoscopic porcedure 3 OP per day Local anaesthsia**	**Endsoscopic procedure 4 OP per day local anaesthsia**
Expenses: Anaesthesia	4,087	4087	3,208	2,406
Expenses: Surgeon	3,090	3,090	3,090	2,318
Expenses: Porter	1,563	1,563	1,563	1,172
Utensils	1,700	6,826	6,826	6,826
Ward + patient care				
Bed day	1.5	0.8	0.8	0.8
Expenses: Admission	5,250	2,625	2,625	2,625
Cost saving				
Microscope	0	1,160	1,160	1,160
Expenses per procedure				
Total Per patient	**15,689**	**19,350**	**18,472**	**15,347**

One-Time Costs

The department has applied to the equipment fund for a total of DKK 1.16 million for equipment, with an expected lifespan of 10 years. This does not include a service agreement after the warranty period for the endoscope or ongoing maintenance and repair costs for instruments.

Literature Review B

This Appendix provides an overview of all the literature found in the literature search, the screening process and a table overview of the literature included in the literature review. The selected studies have informed the understanding of environmental impacts related to patient pathways and surgical procedures in the healthcare sector. The overview in Table B1, supports the literature analyses in Section 7.

Literature search

The Excel file Appendix B - Literature search, contains the complete overview of the literature and its screening process, explained in Section 6.1. It includes the following information for each result.

- Database
- The block category
- Link to the publication
- Title and Abstract
- Sorting Criteria

Overview of literature results

This section provides the Table B1, which is an overview of the final results included after completing the full screening process. The table summarises the results that were reviewed.

Overview of literature results

Table B1. Literature Search Results

Stage	Title	Source
Patient Pathway	Assessing the environmental impact of an anastomotic leak care pathway	(Bischofberger et al., 2023)
Patient Pathway	Carbon footprinting for hospital care pathways based on routine diagnosis-related group (DRG) accounting data in Germany: An application to acute decompensated heart failure	(Zhang et al., 2022)
Patient Pathway	Healthcare-related carbon footprinting - lower impact of a coronary stenting compared to a coronary surgery pathway	(Sack et al., 2024)
Scans	Environmental impact reduction as a new dimension for quality measurement of healthcare services: The case of magnetic resonance imaging	(Esmaeili et al., 2018)
Scans	The carbon footprint of hospital diagnostic imaging in Australia	(McAlister et al., 2022)
Anaesthesia	Environmental and economic impact of sustainable anaesthesia interventions: a single-centre retrospective observational study	(Gasciauskaite et al., 2024)
Surgery	Environmental impacts of surgical procedures: Life cycle assessment of hysterectomy in the United States	(Thiel et al., 2015)
Sugery	How Can the Environmental Impact of Orthopaedic Surgery Be Measured and Reduced? Using Anterior Cruciate Ligament Reconstruction as a Test Case	(Silva de Souza Lima Cano et al., 2025)
Sugery	Instrument and Supply Variability: An Opportunity to Reduce the Carbon Footprint of the Operating Room	(Sathe et al., 2024)
Surgery	Sustainable Operating Rooms: A Comprehensive Framework for Environmental Impact Analysis	(Savio et al., 2024)
Admission	Environmental footprint of regular and intensive inpatient care in a large US hospital	(Prasad et al., 2022)
Patient Transport Consultation	Environmental Benefits of Reducing Patient Mobility and Hospitalization	(Jiménez-Lacarra et al., 2024)

Meeting with Bjarkam

C

This appendix presents summarised notes from two meetings conducted with Carsten Reidies Bjarkam, Head of the Department of Brain and Spine Surgery at Aalborg University Hospital (AaUH). The meetings took place on April 1st and 2nd and the notes were afterward confirmed by Bjarkam. The notes provide insights into the practical implementation of endoscopic procedures at AaUH, including patient selection criteria, surgical workflow, anaesthesia practices, and postoperative considerations. These insights have contributed the modelling and understanding of the endoscopic procedure. The notes are translated from Danish to english using Copilot.

General Information on Endoscopy

- The endoscopic procedure has been in use at AaUH since 2021 – approximately four years (excluding delays due to COVID-19).

Patient Groups

- It is not a matter of choosing between one of the three treatment options: open surgery, endoscopy, or physiotherapy.
- A herniated disc is not an uncommon condition, many people experience it at some point in life due to spinal osteoarthritis, which is very common.
- Those who typically experience a herniated disc are people who are not physically active, have physically demanding jobs, or are genetically predisposed.
- 80 % of people with a herniated disc recover on their own.

Who is Offered Surgery?

- In Scandinavia, there is a general view that surgery involves risk – it can potentially weaken the spine further. Therefore, surgery is only performed when there is a clear indication and physiotherapy has not been effective.
- Surgery is offered to patients with paralysis, issues with urination or bowel control, or those who have completed a 12-week physiotherapy program without improvement.
- Target group:
  - Approximately 20 % of patients are estimated to be eligible for endoscopy.
  - Patients must meet the following criteria:
    - The location of the herniation must allow the endoscope to access the area without difficulty, this depends on the position of the herniation.
    - The disc must have a certain width, and the spinal joints must not be too close together.

Anaesthesia

- Local anaesthesia is not recommended for lumbar disc herniation, as it can be an uncomfortable experience for both the patient and the surgeon, therefore, AaUH only performs these procedures under general anaesthesia.
- Anaesthesia for endoscopic procedures is administered in the same way as for open procedures.

Surgery

- The scar from endoscopy is smaller than from open surgery
  - 3–5 cm for endoscopy procedure.
  - 10–15 cm for open procedure.
- More scans are performed during endoscopy – this is because more images are needed to ensure precise access to the herniation:
  - Endoscopic procedure: 20–36 images taken in two rounds.
  - Open procedure: 8–10 images taken in two rounds.
- Approximately 2 × 3 L of NaCl is used per endoscopic procedure for rinsing – 3–4 cylinders are reused. The fluid is disposed of via the drain.
- Duration:
  - Typically takes 30–45 minutes for an experienced surgeon and an uncomplicated patient.
  - For a surgeon in training, the procedure can take up to 4 hours.

  Personnel in the Operating Room

  - 9 people per procedure:
    * 2 surgeons
    * 2 Operating nurses
    * 2-3 anaesthesia nurses
    * 2 porters
  - All wear surgical attire.
  - Three wear surgical masks, gowns, and gloves (the surgeons and one nurse).
  - All wear lead vests – three also wear lead neck collars.

  Operating Room Environment

  - Lights are turned off when the endoscope is in use.
  - Curtains are drawn.
- Suturing: One stitch.
- There is a high risk that the endoscopic procedure may need to be converted to open surgery in case of complications.

Postoperative

- The same pain management package is used as for open procedure.
- Patients can go home the same day – however, they are typically kept for 6 hours or until the next day, depending on how late in the day the procedure is performed.

Patient Outlook

- Applies to both open and endoscopic procedures:
  - 80 % improve
  - 15 % have mixed outcomes
  - 5 % worsen
- Sick leave:
  - 4–6 weeks for open procedure.
  - 3–4 weeks for endoscopy procedure.
- Rehabilitation is the same for both procedures.

UNSPSC Codes

D

This Appendix presents Table D1, which maps the UNSPSC codes used in the AUH BI database to their corresponding EXIOBASE categories.

Table D1. UNSPSC codes and corresponding EXIOBASE category and the number used in the LCI tables.

UNSPSC		EXIOBASE	
Code	**Name**	**Process**	**Ref to LCI**
10000000	Plants and Animal [...]	Cultivation of plant-based fibres	7
12000000	Chemicals [...]	Chemicals nec	63
13000000	Resin and Rosin [...]	Manufacture of rubber and plastic products	64
14000000	Paper Materials and Products	Paper	54
23000000	Industrial Manufacturing [...]	Manufacture of machinery and equipment n.e.c.	86
24000000	Material Handling and [...]	Manufacture of machinery and equipment n.e.c.	86
26000000	Power Generation [...]	Transmission of electricity	108
27000000	Tools and General Machinery	Manufacture of machinery and equipment n.e.c.	86
30000000	Structures and Building [...]	Construction	114
31000000	Manufacturing Components [...]	Manufacture of machinery and equipment n.e.c.	86
39000000	Electrical Systems [...]	Manufacture of electrical machinery and apparatus n.e.c.	88
40000000	Distribution and [...]	Manufacture of machinery and equipment n.e.c.	86
41000000	Laboratory and Measuring [...]	Manufacture of medical, precision and optical instruments, watches and clocks	90
42000000	Medical Equipment [...]	Manufacture of medical, precision and optical instruments, watches and clocks	90
43000000	Information Technology [...]	Manufacture of radio, television and communication equipment and apparatus	89
44000000	Office Equipment [...]	Manufacture of office machinery and computers	87
47000000	Cleaning Equipment [...]	Chemicals nec	63
48000000	Service Industry [...]	Manufacture of machinery and equipment n.e.c.	86
50000000	Food Beverage and [...]	Processing of Food products nec	43
51000000	Drugs and Pharmaceutical [...]	Chemicals nec	63
52000000	Domestic Appliances [...]	Manufacture of electrical machinery and apparatus n.e.c	88
53000000	Apparel and Luggage [...]	Manufacture of wearing apparel; dressing and dyeing of fur	48
55000000	Published Products	Publishing, printing and reproduction of recorded media	55
56000000	Furniture and Furnishings	Manufacture of furniture; manufacturing n.e.c.	93
60000000	Musical Instruments [...]	Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials	50
70000000	Farming and Fishing [...]	Animal products nec	13
72000000	Building and Facility [...]	Construction	114
73000000	Industrial Production [...]	Other service activities	162
76000000	Industrial Cleaning Services	Chemicals nec	63
78000000	Transportation and Storage [...]	Land transport	122
80000000	Management and Business [...]	Public administration and defence; compulsory social security	137
81000000	Engineering and Research [...]	Computer and related activities	134
82000000	Editorial and Design [...]	Publishing, printing and reproduction of recorded media	55
83000000	Public Utilities [...]	Transmission of electricity	108
84000000	Financial and [...]	Financial intermediation, except insurance and pension funding	129
85000000	Healthcare Services	Health and social work	139
86000000	Education and [...]	Education	138
90000000	Travel and Food [...]	Hotels and restaurants	120
91000000	Personal and [...]	Other service activities	162
92000000	National Defence [...]	Public administration and defence; compulsory social security	137
93000000	Politics and Civic [...]	Public administration and defence; compulsory social security	137
94000000	Organisations and Clubs	Public administration and defence; compulsory social security	137
95000000	Land and Buildings [...]	Construction	114

Transportation

E

This appendix documents the conversion calculation and data sources used to convert transport into physical unit and model patient travel processes in the LCI tables in Section 8.2. The data and calculation presented in this Excel file forms the basis for the transport process included in the LCA

Overview of Excel Woorkbook structure
The Excel file "Appendix E - Transportation" consists of four worksheets:

1. **CSV:** This worksheet contains all transport processes converted to tkm, including both land and and sea transport and the car process modelled for patient travel. These are formatted for direct import into SimaPro
2. **DataEXIO:** This worksheet includes raw EXIOBASE data for land and sea transport across multiple geographies. The data unit is expressed in monetary MEUR2011 and includes all consumptions inputs related to fulfil the given product output.
3. **Calculations:** This worksheets provides the conversion steps to converted EXIOBASE data from monetary units to physical units.
4. **Patient car:**This worksheet contains the underlying data and assumptions used to model the car used on the LCI table for patient travel, including average travel distance, fuel consumption, and CO_2 emissions per km.

LCI Tables F

This appendix presents the LCI data that forms the basis for the LCA of the two procedure: open procedure and endoscopic procedure. The data are complied in the Excel file: Appendix F- Life Cycle Inventory (LCI) dataset, and are structured for direct import into SimaPro.

Overview of Excel Woorkbook structure
The Excel file "Appendix F- Life Cycle Inventory (LCI) dataset" consists of four worksheets:

1. **LCI Open procedure:** The LCI data for the open procedure, including:
    - Procedure kit,
    - Anaesthesia,
    - Single use equipment,
    - Reusable instruments,
    - Medico-technical instruments and
    - Patient pathway
2. **LCI endoscopic procedure:** The LCI data for the endosocpic procedure, including:
    - Procedure kit,
    - Anaesthesia,
    - Single use equipment,
    - Reusable instruments,
    - Medico-technical instruments and
    - Patient pathway
3. **CSV Open Procedure:** The LCI data converted into CSV format and ready to import in SimaPro.
4. **CSV Endoscopic Procedure:** The LCI data converted into CSV format and ready to import in SimaPro.

Note: The file uses the Danish translation of UNSPSC codes. These categories are still aligned with the Corresponding EXIOBASE categories, as explained in Appendix D.

Sensitivity Analysis G

This appendix presents the LCI data used for the sensitivity analysis conducted in Section 8.3.2. The data are in the Excel file "Appendix G - Sensitivity analysis", and are structures for direct import into SimaPro

Overview of Excel worksheet structure
The Excel file "Appendix G - Sensitivity analysis" consists of 12 worksheets:

The six of them contains the LCI data for each sensistivity analysis:

1. S1 - EXIOBASEonly.
2. S2 - EXIOBASE on materials.
3. S3 - Recycling.
4. S4 - 1 use of reusable instruments.
5. S5 - 500 uses of reusable instruments.
6. S6 - 2,000 uses of reusable instruments.

For each of the six scenarios has a corresponding worksheet formatted for direct import into Simapro, following the CSV sstructure.

Note: The file uses the Danish translation of UNSPSC codes. These categories are still aligned with the Corresponding EXIOBASE categories, as explained in Appendix D.

Data Collection H

This Appendix provides an overview of the data collected throughout the study period and are used as LCI inputs. The data are provided in two excel files:

- **Appendix H - overview of data**
- **Appendix H - overview of data (confidential)**

Both files contain detailed information on the specific equipment, reusable and medico-technical instruments, and products used in each procedure, including the products material composition and origin. The confidential version additionally includes unit prices for individual products and devices, which is confidential due to buisness competition factors.

Overview of Excel files
The two excel files, each contains multiple worksheet with data on:

- **Pharmaceuticals:** which tracks the usage of pharmaceuticals across presurgery, durring surgery and postsurgery.
- **Procedure kit:** includes all products with a procedure kit for spinal surgery, used in both of the procedures.
- **single use equipment:** includes all single use equipment identified by SupplyAID. The equipment is used in both the open and endoscopic procedure.
- **Overview of respectively open and endoscopic procedure:** An overview sheet with all the data used as input in LCI tables, contains specific data on weight, material composition, transport, price, usage and origin.
- **Energyuse:** includes calculation of the consumption of electricity, district heating and water per patient.
- **Medico-technical instruments:** contains an overview of all medico-technical instruments observed for respectively the open and endoscopic procedure. which includes their weight, energy use, and price.

Note: The whole excel file is not translated to English

Results

I

This appendix presents the results of the LCA. It includes data from the LCA and sensitivity analyses, comparing the procedures:

- Open procedure (three surgeries)
- Endoscopic procedure (three surgeries)
- Endoscopic procedure (four surgeries)

Overview of Excel worksheet structure
The Excel file "Appendix I -Results" consists of two worksheets:

- **Overview:** Containing the total CO_2-eq for each procedure. and the CO_2-eq breakdown by categories and the sensitivity results investigated in Section 9
- **Total:** Containing all the contributing categories and percentage contribution to the total environmental impact

SupplyAID Data J

This appendix contains raw data from SupplyAID, documented individual lumbar disc herniation surgeries performed in the period between May 2024 and February 2025. the dataset includes data on

- ***Patient demographies:*** *including age and gender*
- ***Surgical details:*** *including date, time, and duration*
- ***single use equipment:*** *used during each procedure*

Overview of Excel worksheet structure
The Excel file "Appendix J - SupplyAID data" consists of three worksheets:

- **Raw data:** contains detailed data for each surgery, including patient ID, surgery duration, and all single use equipment used.
- **Number of patients:** Summarises the number of unique patients by counting distinct patient IDs.
- **Equipment Frequency:** Shows the average frequency of each single use equipment used per procedure, which is used to estimate the average frequency of the single use equipment for one procedure.

Hybrid Processes

K

Appendix K is a document developed by 2.-0 LCA consultants for the Danish Regions. It outlines the methodology behind the hybrid LCA processes used to calculate material specific impacts in the healthcare sector. These hybrid processes were created to improve the accuracy of environmental data by combining detailed data with comprehensive economic data from the EXIOBASE database. The document plays a key role in explaining how the material library was constructed.

1 Introduktion

Denne rapport er et metodedokument, som har til formål at beskrive baggrunden og den anvendte metode til udarbejdelse af materialebiblioteket og tilhørende emissionsintensiteter. Dokumentet går ikke i fulde detaljer med hvert eneste materiale, men beskriver den generelle logik og metode, der er anvendt. Metodedokumentet suppleres med leverance af LCA-modellen, både i SimaPro- og Excel-format, hvor der kan gås i dybere detaljer med den specifikke modellering.

Materialebiblioteket har til formål at estimere klimapåvirkningen af forskellige materialer brugt i sundhedssektoren, hvilket kan informere og anvendes i en strategi for grønne indkøb og bæredygtig udvikling. Derfor er den primære funktion for materialebiblioteket at bidrage til rådgivning og beslutningsstøtte.

I materialebiblioteket er følgende materialer:

Plastik
PET
HD-PE
LD-PE
PP
Silikone
MDPE
SB – Styrenbutadien
PS
Latex
Polycarbonate (PC)
Polyurethane (PU)
ABS
Syntetisk Gummi
Polyester skum
PVC
Papir
Papir
Pap
Tekstiler
Lyocel
Viskose
Polyester: Woven og non-woven
PP: Woven og non-woven
Nylon – polyamider
Bomuld
PET
Metaller
Rustfrit stål
Aluminium
Alufolie
Kobber
Titanium
Guld
Messing
Andet
Simpel elektronik
Mellem elektronik
Kompleks elektronik
Ledning/kabel

Litiumbatterier
Engangsbatterier
Detergent til instrumentvaskere (sterilisering)
Cellulosefibre
Ethylenoxid
Generiske inputs
Transport
Elektricitet

Desuden leveres der generiske produktionsfaktorer for medicinsk udstyr. Disse baseres på Exiobase-processen "_90 Manufacture of medical, precision and optical instruments, watches and clocks" uden inputs af materialer.

Resultater kan findes i **Bilag 1**.

Der leveres resultater for 3 lande. Opdeling sker på basis af klimaintensiteten fra landenes elektricitetsmix baseret på Exiobase v3.3.16. Resultater for hvert land samt opdeling kan findes i **Bilag 1**.

2 LCA-metode

Dette afsnit beskriver den anvendte LCA-metode til konstruktion af LCI-processerne for materialebiblioteket samt beregning af emissionsintensiteter for materialerne.

De to grundlæggende sæt antagelser, der eksisterer for modellering i livscyklusvurdering, er henholdsvis konsekvens og attributiv modellering. (Sonneman and Vigon 2011). Konsekvens modellering er en årsag-virkning baseret tilgang til definition af systemgrænser i LCA (Sonneman and Vigon 2011), og det er karakteriseret ved at bruge substitution til modellering af biprodukter og ved kun at inkludere ubegrænsede leverandører på markedet. Konsekvens modellering anvendes, når undersøgelsen sigter mod beslutningsstøtte, og når resultaterne sigter mod at repræsentere en ændring i efterspørgslen efter de produkter, der er i fokus i LCA.

Attributiv modellering er en normativ tilgang til definitionen af systemgrænser i LCA (Sonneman and Vigon 2011), og det er karakteriseret ved at bruge allokering til modellering af biprodukter (selvom substitution nogle gange også anvendes) og ved at inkludere alle leverandører i markedssammensætningerne (både begrænsede og ubegrænsede). Attributiv modellering anvendes med en række normative regler til at afgrænse aktiviteter og økonomiske eller fysiske strømme, der tilskrives produktet.

Konsekvens LCA og attributiv LCA svarer på forskellige spørgsmål. Konsekvens LCA giver et svar på spørgsmålet: "Hvad er effekten af et valg?" Dette valg kunne være at købe eller producere et produkt (sammenlignet med ikke at købe eller producere produktet) eller at implementere en forbedringsmulighed. Konsekvens LCA er relevant, når virksomheder/beslutningstagere ønsker at kende virkningerne af deres handlinger. Attributiv LCA giver et svar på spørgsmålet: "Hvad er virkningerne fra den del af livscyklussen, der er besluttet at inkludere baseret på de normative allokerings- og afskæringsregler?" Attributiv LCA er relevant, når virksomheder ønsker at rapportere deres virkninger i overensstemmelse med konsensusbaserede retningslinjer/standarder, f.eks. EU's PEF-vejledning.

De to tilgange er omfattende beskrevet i Schmidt and de Saxcé (2016), Weidema (2003), og Weidema et al. (2009). Desuden er konsekvens LCA-tilgangen udførligt beskrevet med eksempler her: https://consequential-lca.org.

Når substitution anvendes, er det vigtigt at skelne mellem bestemmelse (reference) produkter, biprodukter, og materialer til behandling. Referenceprodukter er karakteriseret ved at blive produceret for at opfylde en efterspørgsel, og dermed bestemme produktionsvolumen af den producerende aktivitet, mens biprodukter og materialer til behandling produceres uanset efterspørgslen.

Der er fordele og ulemper ved begge tilgange. En kort opridsning af disse ses i nedenfor.

Tabel 2.1: Fordele og ulemper ved konsekvens LCA og attributiv LCA.

Konsekvens-LCA	Attributiv LCA
Fordele	
• Stræber efter at identificere konsekvenserne af at efterspørge den funktionelle enhed. • Følger ISO 14044 allokeringshierakiet, i.e, den højeste prioriterede made at modellere biprodukter følges. • Baseret på videnskabelige kriterer. • Massebalancer er bibeholdt. • Relativt enkelt at anvende konsistent modellering af biprodukter gennem produktsystemet.	• Tilsyneladende let: Da tilgangen er normativ, kan der træffes ad hoc-beslutninger for at udelukke komplekse problemstillinger. • De fleste branchetilpassede LCA- og GHG-retningslinjer er baseret på attributiv modellering.
Ulemper	
• Usikkerheder forbundet med identifikationen af påvirkede markeder, dvs. "marginale" leverandører. • Svært at kommunikere: Da begrænsede leverandører er udelukket følges den direkte økonomisk forbundne produktkæde ikke altid. Negative miljøpåvirkninger kan misforstås.	• Komplekst (eller umuligt) at anvende samme allokeringsmetode konsekvent i hele produktsystemet. • Ofte følges den lavest prioriterede måde at modellere biprodukter i ISO 14044 allokeringshierakiet. • Masse-, energi- og andre balancer forvrænges. • Allokerede produktsystemer eksisterer ikke i virkeligheden. • Gennemsnitsmarkeder følger ikke nødvendigis årsag-virkningssammenhænge. • Kan føre til misledende resultater, hvis de bruges til beslutningsstøtte.

Da formålet med materialebiblioteket er at levere beslutningsstøtte, sigter den mod at modellere årsagssammenhænge mellem efterspørgslen på produkter og materialer og de tilknyttede virkninger i økonomiske aktiviteter og tilhørende emissioner. Dette gøres ved at skabe en konsekvensorienteret livscyklusmodel, der forbinder udbud og efterspørgsel på produkterne. Denne sikrer, at efterspørgslen efter et produkt er forbundet med de aktiviteter, der forventes at ændre sig som følge af ændringen i efterspørgslen. Studiet bruger en årsag-virkning baseret model, der følger de overordnede krav i ISO 14040 og 14044 kombineret med en konsekvens-LCA modelleringsmetode, som beskrevet i Weidema et al. (2009).

2.1 Konsekvens-LCA

Dette underafsnit præsenterer den anvendte konsekvens-LCA-metode. Som før beskrevet er en af de primære egenskaber ved konsekvens-LCA et fokus på de faktisk påvirkede leverandører, også kendt som ”marginale leverandører”. Her refereres til de leverandører, som vil reagere på en ændring i efterspørgslen på et givent produkt. Dette betyder i praksis at begrænsede leverandører fjernes fra den anvendte markedssammensætning. Leverandører kan være begrænsede af flere årsager: tilgængelighed af ressourcer (fx vandkraft), reguleringer (fx fiskekvoter), hvis det relevante produkt er et biprodukt fra en anden produktionsproces (fx sojaolie fra sojamelsproduktion) eller grundet lav konkurrenceevne (Concito, 2012). Det skal understreges, at baggrundsmodelleringen i Exiobase ikke baserer sig på udelukkende marginale leverandører. Dette er en begrænsning for databasen, som søges forbedret via projektet 'Getting the Data Right': https://www.plan.aau.dk/forskning/dansk-center-for-miljovurdering-dcea/getting-the-data-right. Exiobase er konstrueret via den såkaldte "by-product technology assumption", hvor biprodukter fra hver sektor regnes som undgået produktion af en anden sektor, hvilket svarer til substitution i LCA (Suh et al 2010). Derfor tages der højde for biprodukter i Exiobase, men andre betragtninger for begrænsninger for leverandører er ikke integreret i den nuværende version af databasen.

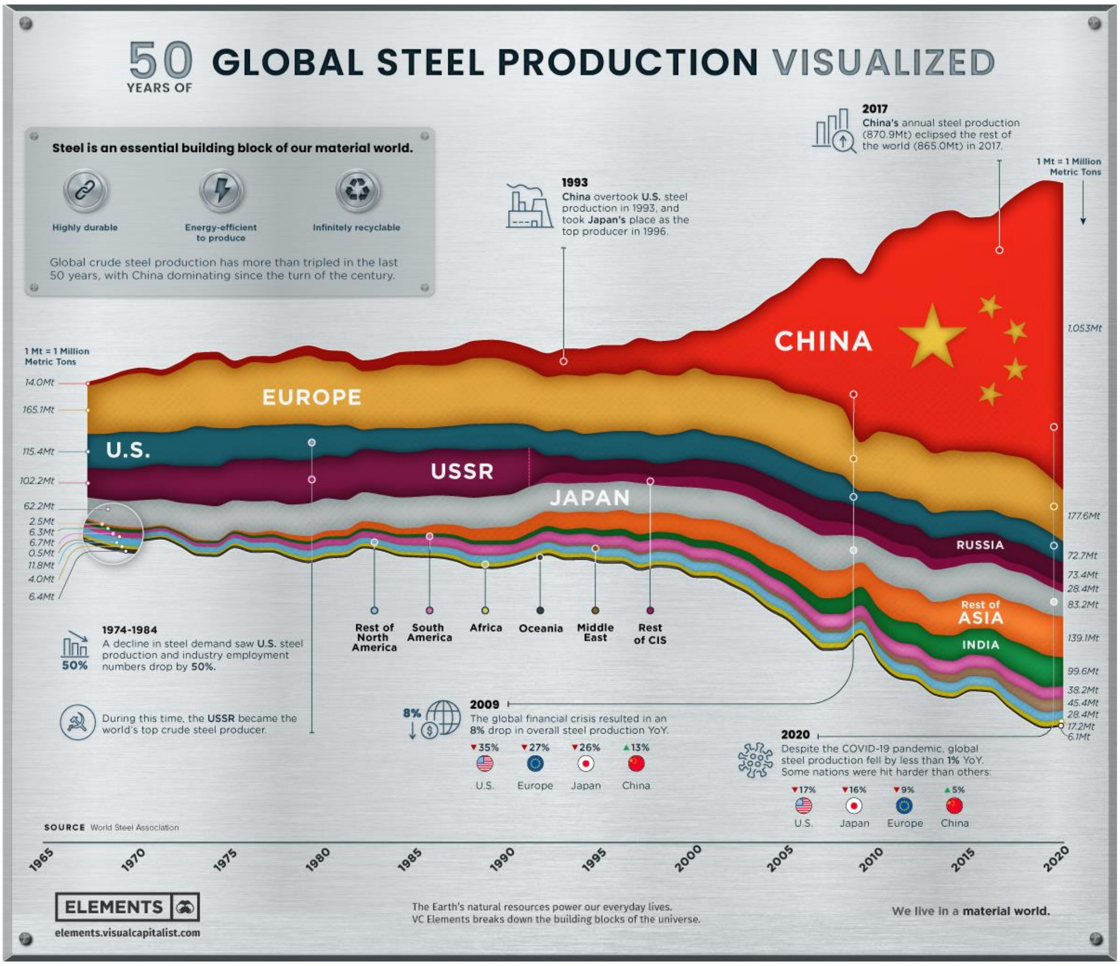
For materialerne i materialebiblioteket analyseres markedsdynamikkerne og en marginal leverandør identificeres. Desuden, som tidligere beskrevet, leveres resultater for yderligere lande i den tredelte kategorisering baseret på klimapåvirkningen forbundet med elproduktion (se **Bilag 2**). Markedsanalysen vises ikke for hvert materiale i dette metodedokument, da fokus er på at beskrive den generelle tilgang. Derfor vises et par eksempler, som illustrerer fremgangsmåden.

Generelt anvendes tidsserier for produktionsdata til identificering af marginale leverandører. Her analyseres ændringer i produktion over tid, hvor producenterne med højest forøgelse identificeres som den mest fleksible leverandør, da denne leverandør inden for tidsperioden har reageret mest på ændringer i efterspørgslen på det givne produkt. Mere information om marginale leverandører kan findes på følgende link: https://consequential-lca.org/clca/marginal-suppliers/

I konsekvens-LCA benyttes systemudvidelse. Systemudvidelse er en måde, hvor biprodukter håndteres gennem udvidelse af systemet til at inkludere de substitutioner, der forekommer i markedet som konsekvens af biproduktet. På denne måde undgås allokering, og alle balancer bibeholdes (Concito, 2012). Derfor er alle biprodukter i materialebibliotekets processer modelleret via substitution, både i forgrundssystemet og i baggrundssystemet. Dermed sikres det, at biprodukter og deres effekt på markedet følger kausalitetsprincipper.

2.2 Markedet for stål

Stålmarkedet er et godt eksempel på et marked, hvor en klar trend kan identificeres ved hjælp af tidsserier over produktion. På **Figur 2.1** ses den globale stålproduktion over tid.



Figur 2.1: Global stålproduktion over tid. Figur fra VisualCapitalist (2021). Datakilde: World Steel Association.

Det er tydeligt, at produktion af stål i Kina nu står for over halvdelen af verdens samlede produktion samt, at den har set gevaldig vækst i nyere tid. Samtidig har resten af verden skruet ned for deres stålproduktion. Det er derfor meget tydeligt, at verdens stigende stålforbrug siden årtusindskiftet har været dækket af en stigende kinesisk stålproduktion.

Dette indikerer kraftigt, at Kina er den marginale leverandør for stål. Selvom der stadig findes stålindustrier i andre dele af verden, viser statistikkerne, at disse er i nedgang. Dette indikerer også kraftigt, at stålindustrien er et globalt marked. Derfor vil en stigning i efterspørgsel på stål ikke påvirke f.eks. stålproducenter i Europa, da de ikke er konkurrencedygtige med Kina. På trods af et eventuelt køb af stål fra Tyskland vil det ekstra hul i markedet dækkes af Kina, da det tilsyneladende bedre kan betale sig at producere stål i Kina. Derfor er Kina valgt som den marginale leverandør af stål. Uanset om stålet købes fx fra en europæisk producent viser statistikken, at europæisk stålproduktion har en nedadgående trend, hvorfor det ikke kan imødekomme den stigende efterspørgsel, hvor Kina derimod kan.

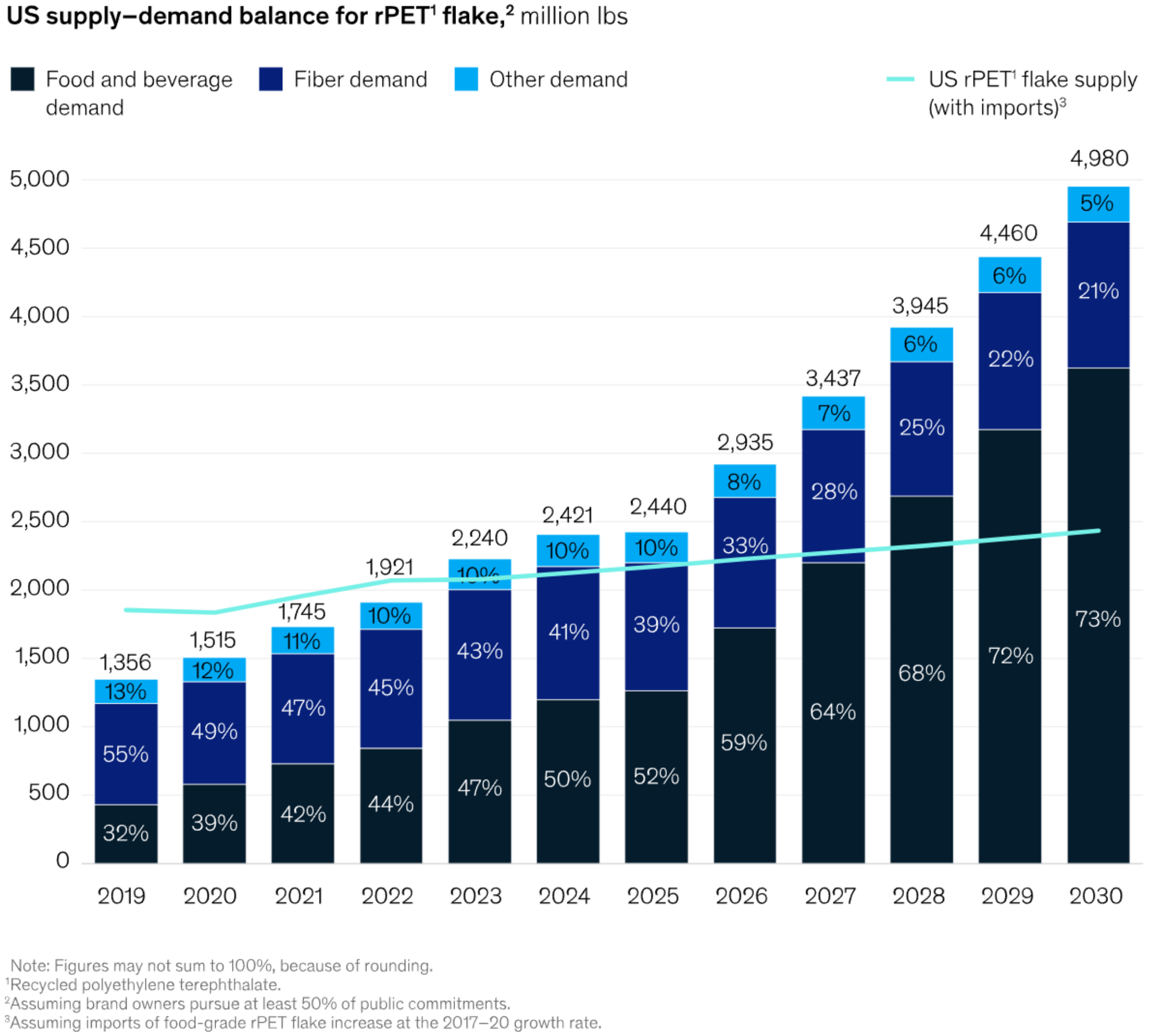
Dog kan det diskuteres hvorvidt en ny business case for europæisk stål kunne opnå, hvis forbrugere af denne stål er villige til at betale en højere pris for specifikt europæisk stål, fx hvis produktionen fører til mindre klimapåvirkning. På den måde vil markedet for stål segmenteres, hvor den mere klimavenlige stål opfylder en anden markedsfunktion. Det centrale her vil være at skabe en kausalitet mellem efterspørgslen på specifikt europæisk stål og en stigende produktion af europæisk stål. En potentiel faldgrube her er, at efterspørgsel på europæisk stål fra en række forbrugere bare vil betyde, at den stål der alligevel produceres i Europa i dag allokeres til disse forbrugere mens andre aftager modtager andet stål. Her kan man risikere, at der ingen ændring vil være i stålmarkedet men blot en fordeling af hvem, der modtager hvilken stål. Derfor er det centralt, at det kan dokumenteres, at effekten af at vælge en specifik stålproducent har en påvirkning på markedet for stålproduktion.

2.3 Genanvendelse

Et andet eksempel på begrænsninger i markedet drejer sig om genanvendte materialer. Samme logik bruges i denne kontekst, nemlig at leverandører af materialer til markedet vurderes i forhold til deres evne til at reagere på en ændring i efterspørgsel.

Modellering af gevinsterne ved genanvendelse kan groft inddeles i to kategorier: ’Recycled content’-metoden og ’closed-loop’-reglen (GHG-Protocol, nd.). Førstnævnte allokerer gevinsten til processen, som bruger det genanvendte materiale, og sidstnævnte allokerer gevinsten til aktiviteten, der sender materialet affaldsbehandling. ’Closed-loop’ kan noteres som være et misvisende navn, da det refererer til en situation, hvor affaldsmaterialet genanvendes til samme formål, hvorfor ’open-loop’ vil være mere retvisende, da det vil referere til en situation, hvor det genanvendte materiale påvirker det generelle marked. Under alle omstændigheder passer logikken med systemudvidelse i konsekvens-LCA, da jomfrueligt materiale substitueres som konsekvens af yderligere leveret affaldsmateriale til genanvendelse (Concito, 2012). Derfor benyttes denne årsag-virkningsmodellering i materialebiblioteket, da det målet er at repræsentere effekten af en ændring i efterspørgsel som konsekvens af et valg, fx i en grøn indkøbsstrategi.

For genanvendte materialer er det relevant at lave denne markedsvurdering for at forstå effekten af en stigende efterspørgsel på genanvendte materialer. Med andre ord besvarer en konsekvens-LCA i denne kontest det følgende spørgsmål: ”Hvad er effekten af specifikt at efterspørge genanvendte materialer?”. Et eksempel kunne være genanvendt plastik. Mængden af genanvendt plastik på markedet er naturligvis afhængig af mængden af plastaffald, der sorteres og genanvendes, hvilket betyder, at den har en naturlig begrænsning. Det afgørende bliver derfor hvorvidt mængden af plastaffald til genanvendelse er fuldt udnyttet. På **Figur 2.2** ses en udbud- og efterspørgsels-oversigt for genanvendt PET i USA.



Figur 2.2: Udbud-efterspørgselsbalance for genanvendt PET i USA. Figur og data fra McKinsey (2023).

Det ses på oversigten, at efterspørgslen på genanvendt PET overgår udbuddet i 2023 og det projekteres at denne ubalance i udbud og efterspørgsel kun vil stige i fremtiden. Dette antages også at gælde for plastik i Danmark. Det står klart, at den begrænsende faktor for genanvendt plastik er relateret til udbuddet og ikke efterspørgslen. Dette indikerer, at fokus bedst lægges i bedre affaldssortering og forbedring af genanvendelsesteknologier, der muliggør, at mere plastaffald kan genanvendes. Derigennem vil et større udbud skabes og mere jomfrueligt plastikproduktion kan undgås. Da plastikforbruget på verdensplan er stigende (PlasticsEurope, 2022) er det også klart, at genanvendt plastik ikke vil kunne dække et stigende forbrug, hvilket betyder, at yderligere jomfrueligt plastik altid vil eksistere på marginalen, så længe verden efterspørger yderligere mængder plastik år for år. Dette er tilfældet selv hvis 100% af plastikaffald kan genanvendes. Af disse årsager modelleres en ændring i efterspørgsel på genanvendt plastik som en ændring i produktionen af jomfrueligt plastik.

Der leveres dog hypotetiske resultater for genanvendt plastik, der er baseret på antagelsen, at genanvendt plastik er en marginal leverandør. Disse resultater viser forskellen på selve produktionen af plastik til markedet gennem genanvendelse, men det noteres og understreges, at disse resultater ikke repræsenterer konsekvenserne ved at efterspørge genanvendt plastik grundet de fornævnte markedsmæssige begrænsninger.

Disse hypotetiske processer for genanvendt plastik er konstrueret med udgangspunkt i Exiobase-processen for genanvendelse af plastik, hvor det undgåede jomfruelige plastik i processen som konsekvens af affaldsbehandling ændres fra at være et biprodukt til at være produkt-flow for processen. Herigennem bliver processen omdannet fra affaldsbehandlingsproces til at være en produktionsproces.

Det skal understreges, at der er tale om volatile markeder, hvorfor store ændringer i både udbud og efterspørgsel over tid er mulige. En begrænsning for genanvendt plastik på nuværende tidspunkt er den direkte konkurrence med jomfrueligt plastik, der ofte kan produceres billigere (OECD, 2018). Dette begrænser muligheden for investeringer i affaldssortering og bedre genanvendelsesteknologier grundet manglende profitabilitet, hvilket er en begrænsende faktor for udbuddet af genanvendt plastik på markedet. Det noteres, at denne begrænsende faktor derfor er meget følsom over for politiske tiltag, især på makro-niveau, der kan ændre markedsforholdene for genanvendelse af plastik. Da andre materialetyper, såsom industrielle metaller, ser langt højere genanvendelsesrater end plastik (OECD, 2018) er plastik ekstra følsom overfor eventuelle politiske tiltag, der kan ændre markedsforholdene. Derfor står det klart, at der på den korte bane er store usikkerheder forbundet med udbud- og efterspørgselsdynamikkerne for genanvendt plastik.

Atherton (2006), en deklaration fra metalindustrien om genanvendelsesprincipper, beskriver markedssituationen for genanvendelse af metaller. Artiklen beskriver hvordan markedet for metalgenanvendelse er modent, hvilket refererer til, at der ikke sendes unødigt metalaffald til f.eks. deponi, da der eksisterer en moden økonomi for genanvendelse, som har en bedre business case. Artiklen beskriver begrænsningerne ved den førnævnte 'recycled content'-tilgang i LCA, grundet begrænsningerne forbundet med mængden af metalaffald. Begrænsningen gør, at genanvendt metal blot flyttes rundt i markedet fremfor, at efterspørgslen på genanvendt metal fører til højere udbud. Atherton (2006) konkluderer derfor, at en 'end-of-life' baseret tilgang bedre fanger de kausale sammenhænge i denne kontekst. Det beskrives, hvordan dette fokus på forbedring af bortskaffelsesfasen kan føre til lavere miljøpåvirkning fra metalindustrien, da forbedringer i produktdesign og bortskaffelsesteknologier kan føre til bedre genanvendelsesrater, hvilket giver mulighed for en større andel af genanvendt metal på markedet, hvilket fortrænger behovet for jomfrueligt materiale. Derfor modelleres en specifik efterspørgsel på genanvendte metaller, som at ville påvirke jomfrueligt metalproduktion. Af samme grund vil levering af metalaffald til genanvendelse modelleres som at fortrænge jomfrueligt materiale.

2.4 Baggrundsdatabase og hybrid-LCA

Materialebiblioteket baserer sig på baggrundsdatabasen Exiobase. Exiobase er en hybrid input-output (IO) LCA database. Tekstboksen nedenfor beskriver Exiobase og dens karakteristika.

Om Exiobase

Exiobase er en såkaldt input-outputmodel. Det betyder, at modellen inkluderer opgørelser over, hvad alle industrier leverer (output) og bruger (input) af produkter i et land. Disse opgørelser er i udgangspunktet baseret på nationalregnskabet. Exiobase skiller sig ud fra traditionelle input-output modeller ved, at den inkluderer inputs og outputs af produkter i både økonomiske, masse og energienheder. Desuden inkluderer modellen alle lande i verden (nogle lande er aggregeret i "resten-af-verden" regioner), som er linket sammen via verdenshandelsstatistikker. Modellen indeholder detaljerede opgørelser over et stort antal emissioner og ressourceforbrug for hver industri i hvert land. Databasen inkluderer:

- 164 industrier/brancher
- 164 produktkategorier, som samlet svarer til alle typer af produkter
- Produktflows opgøres i DKK, ton og MJ
- 43 lande og 5 "resten-af-verden" regioner
- 34 emissioner, 22 ressourcekategorier, arealanvendelse og vand

Data vedrørende massestrømsanalyse for Danmark inkluderer ca. 80 produktkategorier og 17 affaldsfraktioner og alle relevante ressource inputs og emissions outputs. 2.-0 LCA consultants har haft 'technical lead' på udarbejdelse af massestrøms- og affaldsdelen (samt en stor del af emissionsopgørelserne) i Exiobase for følgende EU-projekter:

- FORWAST 2007-2010, http://forwast.brgm.fr
- CREEA 2010-2014, http://www.creea.eu
- DESIRE 2012-2016, http://fp7desire.eu

Exiobase kan bruges til at opstille de beskrevne opgørelser for produktions- og forbrugsperspektiverne for lande, og dermed for gennemsnitlig dansk produktion og forbrug. Disse data bruges som default i de tilfælde, hvor specifikke data for Nordjylland ikke er tilgængelige.

Mere information er tilgængelig her:

- Hjemmeside: https://exiobase.eu
- Publikation med bæredygtighedsindikatorer for alle lande i verden:
- https://www.exiobase.eu/index.php/9-blog/27-creea-booklet

Som IO-database har Exiobase den fordel, at der per definition arbejdes med cut-off på 0%, hvilket vil sige, at hele økonomien er inkluderet. Med andre ord undlades intet fra de forskellige sektorer og LCA-resultaterne vil inkludere f.eks. servicesektor inputs, som ofte undlades fra 'bottom-up' databaser. Exiobase kan klassificeres som en 'top-down' LCA-database, da der tages udgangspunkt i den samlede økonomi, mens en database såsom Ecoinvent kan klassificeres som en 'bottom-up' LCA-database, da der indsamles specifikke data fra forskellige sektorer, som så sættes sammen til konstruktion af en samlet database.

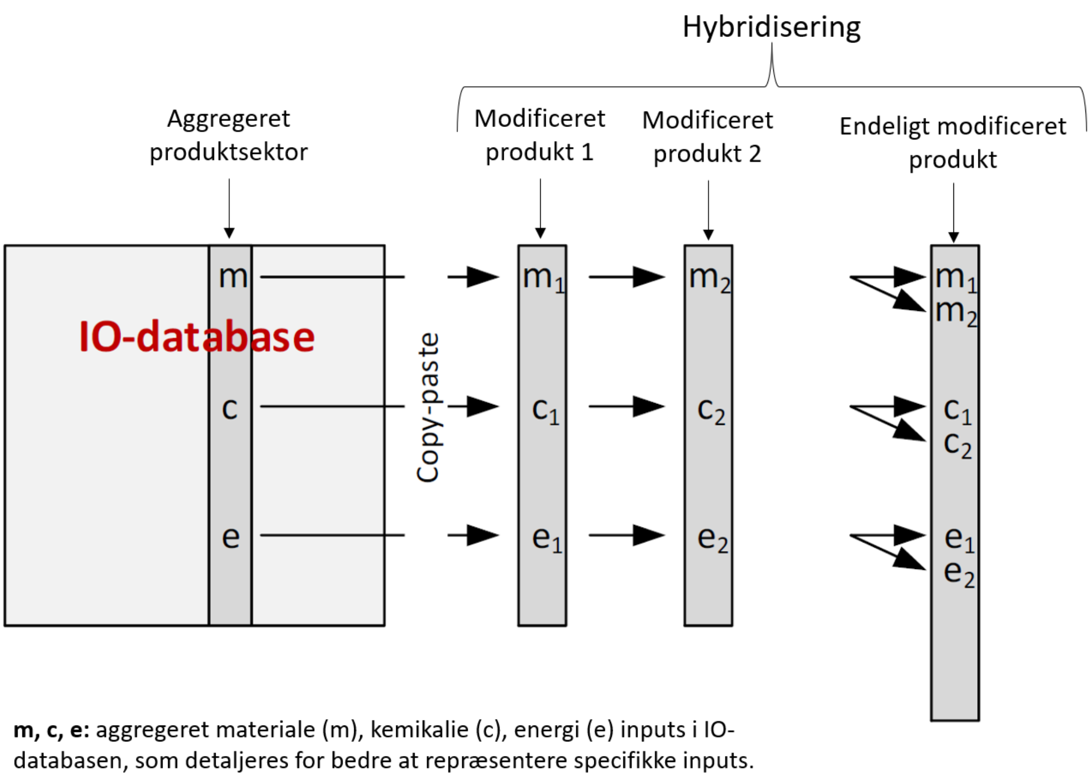
De to tilgange til databasekonstruktion har igen hver sine fordele og ulemper. Disse er kort opridset i **Tabel 2.2** nedenfor. Mere information om Exiobase kan findes i Stadler et al (2018).

Tabel 2.2: Fordele og ulemper ved IO- og proces-LCA databaser.

IO-LCA databaser	Proces LCA-databaser
Fordele: • Komplethed, ingen cut-offs • Generelt god geografisk dækning	**Fordele:** • Høj grad af detalje • Data indsamles på specifikke produkter og specifikke produktionsmetoder
Ulemper: • Aggregerede produktsektorer gør detaljerede resultater på produktniveau udfordrende.	**Ulemper:** • Ikke alle inputs er inkluderet. Cut-offs er ofte tilfældige. • Geografisk dækning er ofte begrænset.

Det kan derfor siges, at IO-databaser såsom EXIOBASE har den store fordel, at der arbejdes med fuld komplethed uden afskæringer, men samtidig den ulempe, at der arbejdes med et lavt niveau af granularitet. I praksis betyder dette, at resultaterne for hver produktsektor ikke forvrænges af eventuelle udeladte input, men samtidig, at opnå resultater på et specifikt produkt i en produktsektor kan være udfordrende.

Af denne grund er materialebiblioteket baseret på en såkaldt hybrid LCA-tilgang, som har til formål at forbedre mulighederne for at modellere specifikke produkter i en produktsektor samtidig med at den fulde komplethed i IO-data bibeholdes. Dette opnås ved at integrere data for mere specifikke i databasen. Denne proces illustreres på **Figur 2.3** nedenfor:



Figur 2.3: Illustrering af konstruktion af hybrid-LCA-processer.

Som illustreret på **Figur 2.3** tages der udgangspunkt i den oprindelige aggregerede produktsektor. Herfra modificeres forskellige inputs såsom materialer, energiforbrug mv. afhængig af tilgængelige data til hybridisering. I eksemplet på figuren laves der tre hybridprocesser fra samme oprindelige IO-proces, hvor de første to (modificeret produkt 1 og 2) bruges som inputs til den endelige hybridproces. Dette kan være relevant for produkter, som har essentielle mellemliggende stadier, der kan være relevant at modellere. Et relevant eksempel er råjern, der laves af jernmalm, og forarbejdes videre til jern. I Exiobase er råjern og jern i samme produktkategori, hvorfor det kan være relevant at adskille de to. I dette tilfælde vil råjernsprocessen være den mellemliggende hybridproces, hvor hybridprocessen for jernproduktion vil have et input af hybridprocessen for råjern.

For alle inputs hvor mere specifikke data ikke kendes benyttes baggrundsværdien i EXIOBASE for den pågældende sektor. Dette kunne f.eks. være jernsektorens forbrug af forsikringsservices eller køb af plastik. Ofte er inputs fra andre sektorer ubetydelige for resultatet, hvorfor der ofte fokuseres på de væsentligste inputs. Det skal understreges, at når der modelleres mellemliggende processer fra samme oprindelige Exiobase-proces, såsom på **Figur 2.3**, er det vigtigt kun at inkludere de generelle inputs fra sektoren én gang, da man ellers vil tælle disse inputs dobbelt. Da eksempelvis råjern og jern hører til i samme proces i Exiobase vil kun én af processerne have den fulde baggrund fra jernsektoren i Exiobase, da denne repræsenterer begge produkter. I materialebiblioteket er det modelleret sådan, at det endelige produkt har disse Exiobase-inputs. Som datakilde til mere specifikke data for de forskellige materialer i materialebiblioteket bruges Ecoinvent-databasen. Her er 'consequential' versionen af Ecoinvent benyttet i overensstemmelse med konsekvens LCA-tilgangen. En oversigt over de anvendte Ecoinvent-processer til hybridisering for de forskellige materialer ses i den supplerende oversigtsfil. Det noteres, at Ecoinvent-databasen EULA skal overholdes, hvilket betyder, at den bagvedliggende modellering ikke må deles med personer uden adgang til Ecoinvent-databasen.

Ecoinvent er en såkaldt proces-LCA-database, som er konstrueret bottom-up. Derfor findes der i Ecoinvent langt mere detaljeret information på specifikke produkter i materialebiblioteket. Dette kunne fx være datapunkter som energiforbrug, materialeforbrug mm. Disse data bliver, som vist på **Figur 2.3**, benyttet til modificering af den relevante Exiobase-proces, hvorigennem hybrid-LCA-processen opnås. Dermed kan LCA-resultater beregnes, der både har kompletheden fra input-outputdata samtidig med den mere detaljerede 'bottom-up' information fra Ecoinvent. På den imødekommes den primære ulempe ved IO-data.

2.5 Forbedring af materialebibliotekets datagrundlag

[Placeholder for tekst omkring Exiobase4 opdatering]

Materialebiblioteket kan i fremtiden forbedres på flere måder. De primære begrænsninger på nuværende tidspunkt er aggregeringer i baggrundssystemet i Exiobase og mangel på optimale forgrundsdata til hybridisering.

Førstnævnte begrænsning omkring aggregering i baggrundssystemet relateres til den generelle udfordring ved input-outputdata som hybridisering søger at løse. Den aggregerede karakter af IO-data vil dog stadig komme til udtryk i en mindre grad, da ikke alle inputs er hybridiseret. Eksempelvis, hvis et produkt i Ecoinvent har et input af et specifikt kemikalie er dette oftest linket til Exiobase-sektoren "Chemicals nec", som inkluderer et vægtet gennemsnit af kemikalier. Problemet kan teoretisk løses ved at hybridisere hvert enkelt input, men af praktiske årsager er der i materialebibliotekets modellering kun fokuseret på hybridisering af de mest væsentligste inputs, mens andre inputs samles i aggregerede kategorier. Denne problematik kræver større databaseudvikling at overkomme.

Til netop dette formål arbejder Aalborg Universitet via projektet 'Getting the Data Right' på BONSAI-databasen (https://www.plan.aau.dk/forskning/dansk-center-for-miljovurdering-dcea/getting-the-data-right), som er en videreudvikling af Exiobase med fokus på disaggregering af aggregerede sektorer (Schmidt et al, 2023). Derfor vil materialebiblioteket og tilhørende emissionsintesiteter have bedre datagrundlag når BONSAI-databasen forventes at være færdiggjort i 2025.

Sidstnævnte begrænsning er baseret på den mere præcise data, der bruges til hybridiseringen af Exiobase. Materialebiblioteket baserer sig primært på Ecoinvent-databasen, som har den fordel, at der er indsamlet data på en lang række produkter. Der er dog ikke data på alle relevante materialer, hvorfor antagelser og estimeringer bliver nødvendige til udvælgelse af disse forgrundsdatasæt. Derudover er den geografiske dækning af Ecoinvent begrænset, hvorfor det kan være udfordrende at få data for det relevante land. Eksempelvis kan Kina identificeres som marginal leverandør, mens Ecoinvent blot har geografisk data for Europa og "resten af verden", hvilket betyder at lokale forskelle i produktionsmetoder kan mistes. Desuden besværliggør brugen af Ecoinvent muligheden for at dele materialebibliotekets LCA-modellering, grundet ophavsret for Ecoinvents datasæt. Af disse grunde er der forbedringspotentiale i at identificere mere og bedre data til hybridisering, der kan føre til resultater, der bedre repræsenterer den reelle effekt af en ændring i efterspørgslen på materialerne. Til en vis grad vil BONSAI-databasen overflødiggøre dele af behovet for denne bedre data, men der vil stadig være detaljegrader udover BONSAI-databasens granularitet, der vil kunne modelleres via yderligere hybridisering.

SupplyAID Business Case L

This appendix includes the business case for the inventory database for the Central Denmark Region, SupplyAID. The appendix gives a further insight into the idea behind SupplyAID and what benefits it provides for the Central Denmark Region. The document is provided on the next page in its original language.

Ansøgning om transformation af materialehåndtering og vareforsyning på operationsgangene. Fra sundhedsfagligt personale til logistikpersonale.

Summary:

Ved at iværksætte en transformationsproces om, at flytte mest mulig af bestillings- og varehåndteringsopgaven på operationsgangene, fra klinisk/sundhedsfaglig personale til logistik faglig personale, og skabe en logistikfaglig forankret og IT understøttet indkøbs- og vareforsyningslogistik kan AUH:

- **Frigive ca. 30 kliniske stillinger på operationsgangene** til kliniske opgaver i stedet for logistik opgaver
- **Reducere udgifterne til varekøb med ca. 25 mio. kr. årligt** ved at minimere spild på operationsgangene
- Forbedre bæredygtighed ved **reducerede affaldsmængder** (reduceret spild), og sikre **sortering af affald** fra operationsstuerne uden belastning af klinisk personale

- Det nødvendiggør investering i ekstra logistikpersonale og i et IT system, **udgifter for i alt 15-20 mio. kr. årligt.**

- Mulighed for at tilvejebringe ca. 30 ekstra kliniske personaler på operationsgangene uden at det koster hospitalet ekstra lønudgifter. **AUH får endda et overskud på 5-10 mio. kr. årligt oveni i de 30 stillinger.**

Økonomioverblik	mio. kr. årligt
Ekstra logistikpersonale inkl. ledelse, back-up m.m.:	ca. 14 mio. kr.
Udgifter til licens/vedligehold af Lagersystem	1 - 6 mio. kr.
Reduceret varekøb (ved minimere spild)	25 mio. kr.
Frigjort klinisk personale fra vareforsyningsopgaver. Ca. 30 stillinger svarende til ca.	15 mio. kr.
Overskud	**20 - 25 mio. kr.**

AUH indkøber for ca. 460 mio DKK årligt på operationsgangene.
En del af varerne bestilles og forsynes af F&S via brikbestillinger i samarbejde med klinikkerne, som hænger brikkerne ud til bestilling.
Den resterende del bestilles, varemodtages mv. alene af det kliniske personale. Hovedparten af varestyringen i klinikken foregår håndholdt dvs. via lister eller excel ark.

Den nuværende opgave for plejepersonalet på operationsstængerne til bestilling, håndtering og genopfyld af varer udgør skønsmæssigt 30-40 årsværk i alt på operationsgangene på AUH. Dette skøn er baseret på erfaringer fra Hjerne-Ryg, estimater fra Hjertesygdomme og oplysninger fra konsulentfirmaer bl.a. MedTronic/IHS som har varetaget vareforsyning på Hjerne-Ryg af ikke brikvarer de sidste par år samt på flere andre hospitaler i Europa.
På Hjerne-Ryg (4 op-stuer) havde man 2,0 – 2,5 fuldtids stillinger beskæftiget med vareforsyning.

Forskellige logistik og vareforsyningsprojekter på operationsgange rundt i verden viser, at der et forholdsvis stort spild af varer. Iht. erfaringstal fra en række EU hospitaler og erfaringer fra Hjerne-Ryg viser at spild typisk udgør 7-10% af indkøbsvolumen. Dvs. på AUH udgør spild på operationsstængerne mellem ca. 30 og 40 mio. kr. årligt.

Potentiale :
Der er et stort potentiale ved at transformere håndtering af vareforsyning i klinikken – med særlig fokus på operationsstængerne – fra at være en opgave forankret og drevet af klinisk personale til at en opgave forankret og drevet af logistikpersonale.

- Der anvendes 30-40 kliniske årsværk på operationsgangene til vareforsyning og logistik. Heraf kan der forventeligt **frigives 25-35 af de kliniske årsværk** ved at flytte logistikopgaverne fra klinisk personale til logistikpersonale.
- Der kasseres i dag varer på afdelingerne for mellem 30 og 40 mio. kr. årligt på operationsgangene på AUH. Heraf kan man forventelige **reducere de årlige omkostninger til spild varer spild med 20-30 mio. kr**.

AUH har helt konkrete erfaringer fra Hjerne-Ryg, hvor man har kørt et pilotprojekt gennem ca. 3 år med stor succes. Hjerne-Ryg har haft MedTronic/IHS inde som eksternt konsulent-/logistikfirma og MedTronic/IHS har haft to medarbejdere gående på Hjerne-Ryg til at forestå alt varelogistik af ikke brikvarer, herunder lager- og forbrugsstyring, bestilling af vare, styring af udløbsdatoer og fakturakontrol. MedTronic/IHS har anvendt lagerstyringssystemet Ingenica til at styre de forskellige opgaver og processer.
Erfaringen på Hjerne-Ryg var, at man havde 8,1% spild/kassation inden man startede op, men nu er nede på 0,1% spild/kassation. Dette svarer til en årlig reduktion i spild på ca. 2,5 mio. kr. uden af afdelingens samlede indkøb på ca. 35 mio DKK årligt.

Handling:
Forsyning & Service forslår at der oprettes en særlig enhed i F&S til at varetage logistikken på operationsgangen samt sikre implementering på alle OP stænger.

Ved at lade F&S varetage hele logistikken og vareforsyningen på tværs af de kliniske afdelinger på AUH – i første omgang specifikt på operationsgangene - sikres det, at opgaven forankres hos uddannet logistikfagligt personale, at der er en ensartet opgaveløsning, samt der kan drages erfaringer på tværs af afdelinger, for bedst mulig opgaveløsning. Ligeledes giver det i langt højere grad mulighed for implementering, anvendelse og få udbytte af IT understøttende systemer.
Det vil være nødvendigt at investere i et lagersystem for at kunne håndtere og realisere de forventede besparelserne ved reduceret spild af varer. Bl.a. til registrering af lagermængder, løbende forbrug, udløbsdatoer, sporing af produktionsnummer, fremskrivning af kommende forbrug mv.

Ved at have F&S personale tilstede på de lokale afsnit fuldtid, vil man ligeledes kunne sikre udførelse af opgaver som til dagligt kan være svært at prioritere for plejepersonale, fx fakturakontrol, håndtering af fejlforsender, opfølgning på bestillinger mv. Det er også forventningen at F&S personale naturligt vil komme til at aflaste klinikken for andre logistik prægede opgaver fx integration med bæredygtighed (affaldssortering og affaldsrapportering), opfølgning for vareforbrug pr. kirurgiske procedurer og evt. operatør samt præpakning og klargøring af varer inden operation

F&S vil ligeledes kunne finde synergier og besparelser i forhold til F&S nuværende håndtering af brikbestillinger, og dermed aflaste det kliniske personale opgave yderligere.

F&S foreslår i første omgang at fokusere på operationsgangene, da det er her, der er langt det største økonomiske udbytte ved at reducere spild samt med den nuværende opgavefordeling, det største potentiale for at frigive klinisk personale fra vareforsynings og logistikopgaver.
F&S forventer, at man også kan igangsætte tilsvarende transformationsprojekt af logstik og vareforsyningsopgaven fra klinisk personale til logistikpersonale på andre kliniske afsnit som fx sengeafsnit, men afventer indtil videre og indtil operationsgangene er i god proces.

Det er vigtigt at HL og de involverede afdelingsledelser støtter op omkring projektet.

Udgifter og besparelser:

Besparelser:
Som beskrevet tidligere kan der realiseres en række besparelser – store besparelser – ved at indføre en mere faglig og IT understøttet vareforsyning forankret i Forsyning & Service. Derudover vil der kunne frigøres mange pleje-/sundhedsfaglige stillinger på operationsgangene til anden aktivitet.

Ved fuld implementering på alle operationsstuer vil man kunne reducere vareforbruget med **ca. 25 mio. kr. årligt ved reduceret spild**.

Derudover vil man ved fuld implementering kunne **frigive ca. 25-35 kliniske stillinger til andre opgaver** på operationsgangene.

Udgifter:
Der vil være en række udgifter forbundet med nærværende forslag. Dels til bemanding af den nye enhed, heraf primært til de nye logistik medarbejderne, som skal være ude på afdelingerne og overtage det kliniske personales logistik og vareforsyningsopgaver.
Derudover udgifter til indkøb og løbende drift/licens af et lagersystem.

F&S forventer – ved fuld drift – at man kan varetage klinikkens nuværende opgaver ved skønsmæssigt 0,9 logistikmedarbejder pr. 1,0 sygeplejesker. Dette inkluderer bl.a. bestilling, lagerstyring, udløbsstyring, fakturakontrol, opfølgning på leveringsdatoer, afsøgning af indkøbs- og leveringsmuligheder, priser, erstatningsprodukter mv. Vi forventer, at det mere entydige fokus på logistik, "stordrifts" fordele, effektivisering af arbejdsgange ved anvendelse af et effektivt lagersystem, samt synergien med nogle de nuværende brikvarer opgaver, gør at F&S kan effektivisere ressource anvendelse til vareforsyningsopgaven, selvom en række af opgaverne vil fylde mere og få øget fokus end klinikken har tid og kræfter til i dag.

Derudover forventer vi at kunne overtage / varetage en række andre og/eller nye opgaver på operationsgangen fx omkring sortering og registrering af affald på operationsstuerne, eller fx pakning og forberedelse af varer til operationer.
Hvor meget eller hvor lidt F&S kan varetage af disse andre opgaver udover de direkte vareforsynings- og logstikopgaver er usikkert, og F&S forudsætter at disse opgaver skal aftales med den enkelte operationsafdeling og formodentlig nødvendiggøre en aftale om ressourcer, da vi i nærværende model og ansøgning ikke har medtaget ressourceforbrug til de disse andre og/eller nye opgaver på operationsgangen.

Lønudgifter til bemanding af den nye enhed udgør i alt forventet **ca. 14 mio. kr. årligt** til logistik, vareforsyning og indkøbs personale på afdelingerne (i alt ca. 25-30 ekstra logistik medarbejdere på afdelingerne) samt til ledelse, specialist og back-up funktioner (systembackup, indkøbere, logistik/dataanalyser mv.)

Derudover vil der være udgifter til IT systemet. I opstarten forholdsvis dyrere pr. operationsgang, men ved fuld drift forventes den årlige udgift til IT vedligeholdelse og/eller licens at udgøre **1 - 6 mio. kr. årligt**, afhængig af hvilken løsning man vælger. Udgiften er baseret på foreløbige prisindikationer fra forskellige mulige aktører.

Lokaler
Der vil være behov for tilvejebringelse af ekstra lokaler og kvadratmeter til at huse den nye enhed og den øgede bemanding. Uagtet at logistikmedarbejderne primært vil være ude i huset, er der behov for del kvadratmeter. Skønsmæssigt 150-200 kvm. Det er væsentligt at enheden placeres tæt på det eksisterende personale der arbejder med logistik og vareforsyning (varemodtagelsen, depotet, brikteamet, logistikkonsulenterne og indkøbsdisponenterne) dvs. i eller ved siden af bygning S04.

Lagersystem:

F&S har undersøgt to forskellige IT spor ift. at tilvejebringe et lagersystem, som kan anvendes til drift af vareforsyning og logistik på operationsafdelingerne (samt på sengeafsnit mm.)

a) Indgå samarbejde med ekstern samarbejdsparter om igangsætning på AUH
Der er indhentet prisindikationer ved både Tecsys og Ingenica som er etablerede lagersystemer i sundhedsvæsenet. Det er bl.a. Ingenica MedTronic/IHS anvender i dag på Hjerne-Ryg.

Det er dog lidt svært at blive sikker på prisstruktur og tilgængelighed på de eksterne lagersystemer.
Prisindikationer på fx Tecsys og Ingenica varierer meget. Fra 3-6 mio. kr. i årlig IT-licens (ved Ingenica) til ca. 10+ mio. kr. årligt (ved Tecsys) dog for en noget større IT pakke. Ligeledes kendes ikke eventuel rabat ved flere brugere/licenser hos Tecsys, da vi kun har et prisestimat fra Tecsys på 10 hjerte stuer og ikke på alle hospitalets ca. 90 stuer. Prisestimatet var ca. 2 mio. kr. årligt for 10 hjerte stuer.
Derudover virker det til, at det kan være svært at kun at købe IT systemet, da noget tyder på, at der er visse samarbejdsaftaler mellem IT leverandører og konsulentfirmaer. Fx er Ingenica prisen på 6 mio. kr. årligt inkl. implementerings omkostninger men også en løbende konsulentydelse fra MedTronic/IHS. Dette giver god mening de første par år, men efter nogle år forventer vi ikke længere at have brug for eksterne konsulentydelser. Uden konsulentydelsen vil udgiften til selve Ingenica systemet ligge på 2-3 mio. kr. årligt.

Hvis det ønskes at indkøbe et eksisterende eksternt lagersystem vil der skulle laves et udbud. Der vil ligeledes skulle laves en databehandleraftale grundet GDPR samt arbejdes med integrering til regionens systemer.

b) Indgå samarbejde med Dias om udvikling af eget IT program
Der er indhentet et prisestimat fra Dias omkring udvikling af et IT program, der kan understøtte de funktioner som er påkrævet.

Dias er en afdeling i region midt, og har erfaring med at udvikle og tilpasse nye IT-systemer til driften bl.a. Medicin-Spild-app'en.

Dias er ikke eksperter i logistik eller vareforsyning, og det vil derfor kræve at F&S står for input omkring fagligheden i programmet, og vil kræve en stor indsat og ressourcer fra F&S at deltage i udviklingen, afprøvning af funktionaliteten m.m.

Systemet vil blive udviklet løbende. Således startes der med et grundlæggende system, der forventes at kunne dække hovedparten af de vigtigste af opgaver – Dette ville kunne være klar efter 3-4 måneder fra påbegyndt kodning.
Dias pris estimat på udvikling af den grundlæggende systempakke er 670.000 kr. og inkluderer bl.a. lagerstyring og datostyring. Det vil være behov for yderligere udvikling af systemet. Hvor meget og hvor omkostningstungt er svært at vurdere for Dias, men det vurderes at der bør afsættes 1,5 mio. kr. årligt de næste to år til yderligere udvikling af funktionaliteter, smartness af arbejdsgange, integration med RM indkøb mv..
Den løbende licens for IT-hosting i Regionen, løbende vedligehold og tilpasninger/udvikling skønnes at udgøre ca. 1,0 mio. kr. årligt fremadrettet.

Det er en fordel at Dias er en regional enhed, og der vil derfor ikke være udfordringer med adgang og integration med RM-Indkøb, og arbejdet kan ligeledes igangsættes og løbende justeres uden at skulle gennemføre et eller flere udbud.

Derudover forventes det færdige program, at kunne udbredes ud til andre afdelinger, såsom klinikker og sengeafdelinger og til andre hospitaler, uden meromkostning, i modsætning til de eksterne systemer, hvor prisen er mere er baseret på antal brugere/antal licenser.

Anbefaling

Det er F&S anbefaling:

- at der oprettes en særskilt afdeling i F&S med fokus på logistikken i OP afdelinger, det er denne afdeling som fremadrettet skal drifte varehåndteringen på OP afdelinger.

- at der indgås der et samarbejde mellem F&S og Dias, hvor Dias betales for udvikling af lagerstyringsprogram til F&S, specielt tilrettet AUH's behov på OP afdelinger.
  Dette for at sikre, at kun features som er brugbare, udvikles.

- at den eksisterende aftale med MedTronic/IHS på Hjerne-Ryg forlænges (4 op-stuer) og samtidig udvides til også at gælde Hjertesygdomme (10 op-stuer). Dog således at det MedTronis/IHS der står for implementeringen på Hjertessygdomme samt løbende IT og analyse support, mens F&S står for selve logistik- og vareforsyningsopgaven både på Hjerne-Ryg og Hjertesygdomme, men kan trække på MedTronic/IHS erfaringer, systemsupport, data m.m.
  Dette vil give AUH og F&S god erfaring og læring med vareforsynings opgaverne i samspil med anvendelse af de forskellige IT funktionaliteter.

- at man i løbet 2024 – og inden udløb af den forlængede MedTronic/IHS aftale - tager stilling, om man ønsker at gå i udbud i forhold til indkøb af et eksternt lagersystem, dette afhængigt af status og erfaringer med det af Dias udviklede lagersystem og erfaringer fra det forlængede MedTronic/IHS projekt på Hjerte og Hjerne-Ryg.

Samlet økonomi:
Det forventes at transformation af vareforsyningen - fra sundhedsfagligt personale til logistikpersonale - på operationsgangene kan være fuldt implementeret efter 3 år dvs. i 2027 evt. allerede i 2026.

Når projektet er fuldt implementeret på alle ca. 90 operationsstuer på AUH vil den økonomiske gevinst være et **årligt overskud ca. 20 – 25 mio. kr**. inkl. værdien af de 30 frigjorte plejestillinger.
Udvikling og anvendelse forventes at være den økonomisk mest fordelagtige løsning og vil derfor skabe et forventet årligt overskud på 25 mio. kr.
Hvis man i stedet indregner en ekstern IT lagerløsning vil overskuddet i stedet forventelig udgøre 20-23 mio.kr. iht. de foreløbige prisestimater.

Der vil i starten af processen være større udgifter end besparelser, dels pga. opstart og udviklingsomkostninger og dels pga. en vis oplæringsperiode før man kan overtage/frigive eksisterende personale og endelig fordi der vil være en vis forsinkelse fra undgået kassation til sparet indkøb.

Der er anvendt følgende forudsætninger i nedenstående eskaleringsplan:
- Nyt logistikpersonale ansættes 6 mdr. før der indregnes frigjort/sparet klinisk personale
- Reduceret spild forventes at få effekt 6 mdr. efter opstart af OP-afsnit.
- Den udviklede Dias IT løsning forudsættes anvendt. I fald det i stedet ender med indkøb af et eksternt lagersystem forventes de årlige udgifter til licens/vedligehold at blive 2-5 mio. kr. højere end ved Dias løsning, og dermed det samlede overskud tilsvarende 2-5 mio. kr. lavere.
- Der forudsættes en standard pris på ca. 15.000 kr. pr. kvm. ved byggeri/etablering af lokaler.

Økonomioverblik - eskaleringsplan	År 2024	År 2025	År 2026	År 2027
Lønudgift logistikpersonale inkl. ledelse,indkøb,back-up:	5,0	10,0	14,0	14,0
Udgifter til licens/vedligehold af Lagersystem	0,2	0,6	1,0	1,0
Udviklingsudgifter til lagersystem ved Dias	1,5	1,5		
Etableringsudgifter lokaler	1,5	1,0		
Reduceret varekøb (ved minimere spild)	4,0	12,0	20,0	25,0
Frigjort klinisk personale fra vareforsyningsopgaver. Antal stillinger	ca. 5 årsværk	ca. 15 årsværk	ca. 25 årsværk	ca. 30 årsværk
Frigjort klinisk personale fra vareforsyningsopgaver. Frigjort/sparet lønudgifter	2,5	5,0	12,5	15,0
Resultat ialt (mio. kr. årligt)	**-1,7**	**3,9**	**17,5**	**25,0**