CHALMERS
UNIVERSITY OF TECHNOLOGY

Sustainable Warehousing: Analysing a Cross-Dock Facility for a Greener Future

Master's thesis in Supply Chain Management

Francis Senghore
Jakob Yosef Jakob

DEPARTMENT OF TECHNOLOGY MANAGEMENT AND ECONOMICS
DIVISION OF SUPPLY AND OPERATIONS MANAGEMENT

CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2023
www.chalmers.se

Report No. E2023:111

REPORT NO. E2023:111

Sustainable Warehousing: Analysing a Cross-Dock Facility for a Greener Future

Francis Senghore
Jakob Yosef Jakob

Department of Technology Management and Economics
Division of Supply and Operations Management
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2023

Sustainable Warehousing: Analysing a Cross-Dock Facility for a Greener Future

Francis Senghore
Jakob Yosef Jakob

Report no. E2023:111
Department of Technology Management and Economics
Chalmers University of Technology
SE-412 96 Gothenburg
Sweden
Telephone + 46 (0)31-772 1000

Gothenburg, Sweden 2023

Sustainable Warehousing: Analysing a Cross-Dock Facility for a Greener Future

Francis Senghore
Jakob Yosef Jakob

Department of Technology Management and Economics
Chalmers University of Technology

SUMMARY
This case study of a logistics service provider (Company X) is an example of how companies respond to customer demands and stakeholder expectations by prioritising sustainability. Motivated by one of its major customers, a leading manufacturer of vehicles and machinery, Company X is trying to introduce more sustainable practices. Therefore, Company X wants to replace diesel forklifts with electric ones, thereby reducing its environmental footprint.

The thesis examines Company X's requirements and challenges in creating an optimal environment for introducing a fully electric forklift fleet. The methodology used is a mixed method and case study, using qualitative and quantitative approaches to fully understand the company's current situation and the factors affecting its sustainability goals. The findings provide several recommendations for Company X. The first recommendation highlights the importance of making sustainability goals visible and promoting a culture of sustainability. The second suggests transitioning to a new electrified forklift fleet with Li-ion batteries as the power source. The third proposes improvements to the infrastructure and facilities, as well as moving the charging area to a shielded area separate from the open gates.

Finally, it is also recommended to improve the layout and operational processes through a category-based layout. This thesis provides valuable insights and practical guidance for Company X and contributes to a broader understanding of sustainable practices in the logistics and warehousing industry. Company X can make significant progress towards more environmentally conscious organisations by incorporating industry best practices and adopting effective strategies. The recommendations will help the company achieve its sustainability goals and optimise its processes.

Keywords: Electrical Forklift, All-Electrical Forklift fleet, Sustainable Cross-Docking, Cross-Docking Layout

Acknowledgement

As we conclude this thesis, we would like to thank those who have contributed to our thesis sincerely. Although we cannot name everyone, we are grateful to everyone who contributed in some way to our research. We thank our examiner and supervisor Riikka Kaipia for her unwavering support. We also thank Robert Lumsden and Thomas Zetterberg, our supervisors at Company X, for their valuable help. We are also grateful to all the people in Company X who generously participated in the interviews. We also thank the support of our friends and family.

Table of content

1. **Introduction**

In this part of the thesis, an introduction of the background of the case company Company X is conducted together with a purpose for the thesis, that describes the scope briefly with an expected outcome. Three research questions were formulated based on the purpose of the report. Lastly, limitations will be set for the thesis to ensure the purpose is fulfilled and followed correctly.

1.1. Background

The global push towards sustainability has increasingly become a pressing issue for companies in recent years. With the signing of the Paris Agreement in 2015, the world has committed to limiting the rise in global temperatures to well below 2 °C above pre-industrial levels, which has prompted companies to re-evaluate their practices and strive for greater sustainability (United Nations, 2015).

Companies recognise that sustainability is a social and ethical responsibility and key to long-term business success. Sustainable practices can improve financial performance, reduce risk, and enhance reputation. Additionally, as consumers and investors become increasingly environmentally and socially conscious, companies that are seen as sustainable are more likely to attract customers and investment capital (IBM, 2023).

There has been a growing trend towards electrification in the industrial sector in recent years. Companies across various industries, including logistics and warehousing, are increasingly switching from fossil fuel-powered machines to electrically powered ones. This shift is driven by several factors, including a desire to reduce greenhouse gas emissions, improve energy efficiency, and meet increasingly stringent environmental regulations (Deloitte, 2020).

Several studies have demonstrated the benefits of switching from fossil fuel-powered machines to electric ones. For example, a study by the International Energy Agency (IEA, 2022) found that using electric machines in the industrial sector could significantly reduce greenhouse gas emissions and energy consumption. A European Commission report by De Bruyn et al., (2020) also found that the widespread adoption of electrically powered machines in the logistics and warehousing industries could substantially reduce CO_2 emissions.

Company X has been at the forefront of the logistics industry since the early 1900s, offering comprehensive solutions covering freight, warehousing, and transport services. Company X is a leading provider of shipping and logistics solutions with a long history of delivering high-quality services to clients worldwide. With the headquarter located in Scandinavia, Company X has approximately 10,000 employees in over 20 countries.

This case highlights how companies are responding to the demands of their customers and stakeholders by prioritising sustainability in their operations. In addition to the broader reasons for companies to become more sustainable, Company X is motivated by the specific demands of its customers. One of its biggest customers, one of the world's leading original equipment manufacturers (OEM), strongly desires its suppliers to adopt more sustainable practices. As a result, Company X is looking to replace its diesel forklifts with electric forklifts at its warehouse in Gothenburg, Sweden. This move will reduce its environmental footprint and improve its bottom line.

1.2. Purpose and Research Questions

This thesis aims to investigate what Company X needs to do to create an optimal environment for introducing an all-electric forklift fleet. Areas of investigation include the forklift fleet, layout, operation processes, facility, and infrastructure. Firstly, by looking at the current state of the mentioned areas. This is to map out and understand the current challenges of replacing its diesel forklifts with electric ones, secondly, by giving recommendations for solutions and requirements for Company X to align with the stakeholders' sustainability requirements.

The following questions will be answered to achieve the report's purpose:

A study of the forklift fleet, layout, operation, infrastructure, and facilities will be conducted to understand Company X's current situation. That is why the research question one (RQ1) was formulated.

RQ1: What is the present state of Company X's forklift fleet, layout, operation, infrastructure, and facilities?

The second research question (RQ2) has been formulated to understand Company X's challenges in creating an optimal environment for introducing an electric truck fleet. The challenges related to making Company X more sustainable will be mapped out and analysed.

RQ2: What challenges does Company X face when creating an optimal environment for an all-electrical forklift fleet?

Finally, recommendations are given to Company X on how to create an optimal environment for introducing an electric forklift fleet, as well as suggestions on the type of forklift to be selected. Company X should use the recommendations to become more sustainable. That is why research question three (RQ3) was formulated.
RQ3: What recommendations on solutions are most appropriate for Company X from a sustainable point of view?

1.3. Limitations

This study is limited to Company X's facility in Gothenburg. It will be limited to the cross-docking (CD) area at Company X. The operational data is limited to the data from internal documents provided by Company X.

2. Literature review

This literature review will study topics such as sustainable warehouse management, layouts for cross-docking facilities, processes for cross-docking operations and material handling equipment. This to get a better understanding of the topics and to base our recommendations on the research.

2.1. Sustainable warehouse management

Sustainable warehouse management has gained considerable attention in recent years due to the growing concerns about the impact of warehouse operations on the environment and society. This literature study aims to provide a comprehensive overview of sustainable warehouse management, its characteristics, environmental impacts, best practices, economic benefits, and future trends. The following sections will discuss these topics in detail.

2.1.1. Sustainable warehouse

Tan et al. (2009) defines sustainable warehouse management as managing operations to minimise environmental impacts and maximise economic and social benefits. This definition is supported by Rodrigue (2020), who identifies three main elements of sustainability: social equity, economic efficiency, and environmental responsibility. Social equity involves the fair distribution of resources and opportunities among individuals and institutions without implementing discriminatory practices. Economic efficiency optimises resource and labour usage and provides goods and services that meet market demand. Environmental responsibility involves reducing the footprint of human activities to ensure that the environment can accommodate them (Rodrigue, 2020).

Environmental legislation impacts many organisations and will increasingly require new approaches to managing and reducing energy and carbon emissions. Richards (2022) emphasises that each country or group of countries will have its environmental legislation. Environmental legislation has made carbon the 'new currency' in a 'carbon economy'. This new economy means organisations must be aware of their 'carbon footprints', where their emissions come from, and how to reduce them. This highlights the importance of stimulating resource-efficient and low-carbon action to achieve green goals such as reducing carbon emissions and developing low-carbon businesses. Sweden's Ministry of the Environment (2020) mentions four significant opportunities to reduce industrial emissions. In Sweden's long-term strategy for reducing greenhouse gas emissions, these opportunities include switching from fossil raw materials and energy to renewable raw materials and energy carriers, improving process and material efficiency, moving entirely to the basic process, for example through electrification, and introducing carbon capture and storage technologies, which can reduce both fuel-related and process-related emissions.

Certification systems, such as LEED and BREEAM, are used to determine the sustainability of warehouses (Boverket, 2023). LEED assesses warehouses based on nine categories, including integrative processes, location and transportation, sustainable sites, water efficiency, energy and atmosphere, material resources, indoor environmental quality, innovation in design, and regional priority (Sweden Green Building Council, 2023). BREEAM assesses warehouses based on management, energy, health and well-being, materials, transport, water, waste, pollution, land use and ecology (Zeinal Hamedani & Huber, 2012).

Tan et al. (2009) emphasises the need for businesses to promote sustainability within their operations, and throughout their entire supply chains, to remain competitive. Sustainable supply chain management has several benefits, including increased brand appeal, sales loyalty, and stakeholder satisfaction, as well as reduced negative impacts on society and the environment. Furthermore, a sustainable supply chain would improve transparency and visibility along the chain, enabling companies to respond quickly to changes in the market and other situations. These benefits highlight the importance of incorporating sustainability into supply chain management strategies.

2.1.2. Environmental Impacts of Warehouse Operations

The environmental impacts of warehouse operations includes, but aren't limited to, energy consumption, greenhouse gas emissions, and waste generation. Sustainable practices such as green building design, renewable energy sources, and waste reduction strategies should be implemented to reduce these impacts. However, compared to transportation, little attention has been given to evaluating the consequences of warehousing within the supply chain (McKinnon, 2015).

Assessing the overall impact of warehousing requires consideration of the relative scale and trends in the extent of the land and the direct energy used, the emissions produced, water consumed, and embedded energy contained in building materials (McKinnon, 2015). Warehouses account for a substantial proportion of global use of energy, and greenhouse gas emissions from buildings exceed those from transport Bartolini, (2019). In the United Kingdom, warehouses account for around two million tonnes of oil equivalent energy use, compared to about eight million tonnes of oil for heavy vehicles and approximately five million tonnes for light vehicles (DECC, 2013). Although transport is the main logistical contributor to green gas emissions, warehousing is significant and must be fully considered in supply chain studies (World Economic Forum, 2009).

The main areas of energy use in United Kingdom warehouses are heating and lighting, that according to Richards (2022) has the potential of a 16% reduction in emissions. Warehousing is viewed as a supply chain activity with significant potential for cutting carbon emissions (World Economic Forum, 2009). Therefore, it is crucial to incorporate sustainable practices into warehouse operations to reduce the environmental effects and help create a more sustainable and green future.

2.1.3. Factors Affecting Sustainability Performance

According to Ali et al. (2023), the theoretical framework of contingency theory, organisational behaviour and performance are shaped over time by internal and external factors, which are also shaped by the operating environment. When striving for sustainable performance, organisations are encouraged to broaden their focus beyond operational and financial aspects and instead emphasise the measurement of progress. Using sustainability indicators, organisations can effectively measure their progress towards sustainable goals (Ali et al., 2023).

Both external and internal factors within an organisation can act as motivators or forces that drive the implementation of environmentally friendly and sustainable practices (Ali et al., 2023). Such practices should be consistent with the expected outcomes of sustainability performance, ensuring consistency and compatibility. In order to maximise sustainable performance results, addressing unforeseen factors such as socio-economic and environmental uncertainties, as well as structural, functional and operational complexities within the organisation, becomes essential (Ali et al., 2023).

The ability of organisations to be at the forefront of sustainability depends on their ability to manage unforeseen environmental factors, implement sustainable actions and continuously analyse sustainability performance (Ali et al., 2023). It is important to note that external contingencies are beyond management's direct control, requiring strategic planning to manage them effectively. According to Ali et al. (2023), organisations must consider a comprehensive understanding of the factors affecting sustainability, strategic management of unforeseen events and a continuous evaluation of sustainability practices when striving for sustainable performance.

2.1.4. Ranking of Sustainable Performance Measures and Practices

Ali et al. (2023) conducted a study to rank the best practices and measures for achieving sustainable warehouse performance. The study involved ten engineering and business management experts, each with a minimum of 10 years of work experience. Seven experts had hands-on experience in industrial warehouse operations, while three were corporate consultants with academic affiliations.
The research encompassed three phases. In the first phase, a literature survey and fuzzy Delphi method were employed to identify sustainable-green practices and performance measures for achieving sustainable performance in warehouses. The second phase utilized the Best Worst Method (BWM) to determine the pairwise comparison-based ranking of sustainable practices. Lastly, the CoCoSo (Combined Compromise Solution) approach was applied in the third phase to evaluate the sustainable performance of warehouses by considering the adoption of sustainable practices (Ali et al., 2023).

Based on the ranking provided by the ten engineering and business management experts, the priority order of sustainable-green practices was determined as follows: 1) green operations, 2) implementation of green policies and strategies, 3) employee training about green practices, 4) adoption of green transportation, 5) green work environment and culture, 6) adoption of eco-friendly waste management practices, 7) implementation of environmental monitoring and control, and 8) development of green building and infrastructure (Ali et al., 2023). In terms of sustainable performance measures, the study revealed that the most significant indicator was the decrease in energy consumption costs attributed to implementing sustainable, eco-friendly operations. The second-ranked performance measure was the reduction of toxic emissions, as warehouses were required to adhere to emission control policies. Formulating employee welfare policies and implementing supervision and control measures led to a decrease in the annual number of environmental accidents, placing it at the third rank. A cooperative work environment that fostered employee motivation was ranked fourth (Ali et al., 2023).

The study found that green operations and technological integrations improved work efficiency and worker output while reducing solid waste, ranking it sixth. The performance measures of improved market share and decreased inventory levels were ranked at seven and eight, respectively. The organization's global image and carbon footprint were evaluated as the ninth rank, followed by the increase in investment recovery of excess inventory at the tenth rank. The bottom three performance measures were improved capacity utilization (11^{th} rank), reduced electricity consumption (12^{th} rank), and increased sale of scrap and used materials (13th rank) (Ali et al., 2023).

2.1.5. Best Practices in Sustainable Warehouse Management

Ali et al. (2023) emphasises the significance of several key factors contributing to the sustainability performance of warehouse operations. Energy-efficient operations, enabled by advanced technologies, are crucial in reducing resource consumption, improving economic performance, and optimising future demand. Ensuring optimal management of packaging scrap, including classifying incoming and outgoing materials and applying CD techniques, contributes to resource saving. These practices lead to cost and time savings while reducing CO2 emissions. Green transportation practices are essential in reducing fuel usage and emissions. Strategies such as using high-quality fuels, using alternative fuels for long-distance deliveries and introducing electric vehicles are effective in achieving these goals (Ali et al., 2023).

Integrating resource-saving processes into warehouse building design and operations is vital for promoting sustainability (Ali et al., 2023). This can be achieved through air-cooled equipment, eco-friendly building materials, and water conservation measures like rainwater harvesting. Considering product nature, location, climate conditions, and facility requirements, proper insulation and temperature control measures contribute to energy efficiency. Additionally, addressing noise control through green building practices further enhances sustainability (Ali et al., 2023).

Employee training programs focusing on energy-efficient practices and operations are crucial in fostering a sustainability-oriented mindset (Ali et al., 2023). Regular training enhances work behaviours and influences employees' lifestyles and thought processes, fully promoting sustainable practices. Establishing a sustainable work culture is essential for transforming work methods and preserving ethical values. Encouraging cleanliness, reduced energy consumption, and the proper use of machines and appliances helps conserve energy. When managers adhere to sustainable practices, they inspire employees to follow suit, thereby improving social aspects within the sustainable supply chain (Ali et al., 2023).

Green and eco-friendly strategies and policies, including sustainable corporate and low-carbon policies, provide essential guidance for sustainable warehouse operations. Regular sustainability reporting and monitoring mechanisms ensure the integration and continuous evaluation of sustainable practices. These strategies and policies are often shaped by external factors, such as government pressures, emphasising the need for organisations to adapt to external contingencies (Ali et al., 2023). Implementing effective monitoring and control measures is vital for assessing the impact of sustainability strategies and policies. Formal and informal evaluation methods help gauge the effectiveness of environmental initiatives, providing valuable insights for further improvement (Ali et al., 2023).

In addition to sustainable practices, case studies of warehouse operations demonstrate significant environmental impact reduction through energy-efficient measures. For example, Rhenus Logistics, a Dutch logistics company, achieved the highest BREEAM rating for its airtight warehouse in Tilburg, Holland (Richards, 2022). The facility's large glass windows allow ample natural light, reducing electricity consumption by 70%. With over 13,000 solar panels, the building generates sufficient energy to power its operations and contribute to the country's electrical grid (Richards, 2022).

Other best practices in sustainable warehouse management include reducing energy consumption from lighting, heating, and cooling systems (Richards, 2022). Implementing energy-efficient lighting, installing movement sensors and timers, and utilising natural light through skylights and clerestory windows help minimise lighting costs. Similarly, using zoned and time-controlled thermostats, time controls on equipment not required after business hours, and incorporating sunlight reflectors and mobile air handling units contribute to reducing heating and cooling expenses (Richards, 2022).

Warehouse operators can generate their energy to offset CO2 emissions (Richards, 2022). Initiatives such as installing solar panels on rooftops, as planned by Amazon for its fulfilment centres worldwide, or deploying large-scale roof-mounted solar panel arrays, as accomplished by Marks & Spencer, significantly contribute to sustainable energy production. Additionally, wind turbines and biomass energy production offer viable options for generating low lifecycle emissions at a reasonable cost (Richards, 2022).

2.1.6. Future Trends in Sustainable Warehouse Management

Emerging trends and directions in sustainable warehouse management include using new technologies, increased collaboration, partnerships, and integrating sustainability into supply chain management (Richards, 2022). For instance, some warehouse developers, investors, and occupiers are interested in securing the WELL Building Standard, which focuses on ten broad concepts: water, nourishment, light, fitness, movement, thermal comfort, mind, sound, materials, and community. Meanwhile, outside of the warehouse environment, clean air zones in urban environments may impact the location of future warehouse development. Another possible trend could be to ban petrol and diesel vehicles from certain parts of the urban road network, which could influence how warehouses are operated regarding sustainability (Richards, 2022).

2.2. Cross-docking Layout

The efficiency and effectiveness of warehouse operations are critical factors in a supply chain. Cross-docking minimises handling and storage costs, by minimising the time products spend in the warehouse. The design and layout of CD facilities play a crucial role in operational efficiency, safety, and space utilisation. One strategy that has gained widespread popularity in recent years is CD, which involves transferring goods from incoming trucks to outgoing trucks with minimal storage. Various layout designs will be introduced, including fixed, category-based, and flexible. This literature review will examine the fundamental concepts of CD (Richards, 2022).

2.2.1. Cross-Docking

According to Richards (2022), CD is a logistics strategy that involves moving goods from incoming trucks to outgoing trucks with minimal storage of goods. Cross-docking is best suited for goods in high demand since it has a predictable demand pattern and can be easily identified and sorted. Perishable goods such as food and medicines are often ideal for cross-docking. Cross-docking needs the full support of suppliers in terms of clear labelling and advance notice of arrival, accurate and on-time delivery, and coordination for the goods to be consolidated accurately. A pick-by-line system can be used for cross-docked products for multiple store deliveries, where items are picked from a pallet and allocated directly to a store. Just-in-time systems also rely on cross-docking, where manufacturers deliver parts to a cross-docking, where they are assembled and delivered to the line in sequence (Richards, 2022).

The design and layout of cross-docking facilities can significantly impact operational efficiency, safety, and space utilization (Richards, 2022). Facility elements such as renewable energy sources, temperature control, noise pollution, and daylight usage are essential when cross-docking facilities are constructed. The use of technology, such as automation and robotics, can also improve the efficiency of CD design. Different types of layout designs exist for cross-docking facilities, including fixed, category-based, and flexible (Richards, 2022).

2.2.2. Fixed Layout

This approach establishes a fixed layout for the storage area, where the goods being delivered are always put in the same place at the CD (Horta et al., 2016). In a traditional warehouse, if the storage requirements exceed the storage capacity, the layout remains the same, and only some rack locations may remain empty. However, different adjustments can be made to the fixed layout, making it more flexible. An adjusted fixed base layout gives the goods a specific placement for a period, such as a year (Vis & Roodbergen, 2011).

Fixed layouts offer advantages such as ease of implementation and a familiar, stable working environment for employees (Vis & Roodbergen, 2011). However, they need more flexibility and can adapt to changes in daily activities or workload fluctuations. Work efficiency can vary significantly daily, and a fixed layout can quickly become outdated if circumstances change. Therefore, it is essential to regularly check and adjust fixed layouts to ensure they remain effective and meet evolving needs (Vis & Roodbergen, 2011).

2.2.3. Category-Based Layout

To introduce more flexibility to the layout, CDs could use category-based layouts. Category-based layouts use limited situations based on the facility's activity level (Horta et al., 2016). For example, busy, average, and quiet days each have a different fixed layout for each situation. In determining the appropriate layouts, a forecast is made for the expected demand in the facility, where the forecast will dictate the decision of the layout. Within the forecast, there is an analysis of different factors that need to be taken into consideration (Horta et al., 2016).

Factors such as required storage space, the number of customer orders, or the total number of stops can be used, but they may be correlated, creating issues when deciding the layout (Vis & Roodbergen, 2011). For instance, the total number of stops made on a day is likely to be higher on a day with many customer orders. It is crucial to consider the number of categories required and the number of different layouts that should be used. Category-based layouts offer added flexibility compared to fixed layouts, but they require employees to adapt to different layouts. If this were an issue, only a few categories should be used. However, if efficiency gains outweigh familiarity concerns, more categories might be an option (Vis & Roodbergen, 2011).

2.2.4. Flexible Layout

The concept of a flexible layout involves selecting a different layout each day based on the anticipated activity level. The successful implementation of flexible layouts relies heavily on the availability of relevant information prior to the start of the day (Horta et al., 2016). If no information is available, it becomes impractical to employ flexible layouts. However, in most cases, some information is known, such as the number of loads to be handled or the number of customer orders for the day. Given the objective of developing a practical method, it is not feasible to determine the optimal layout each day using fixed layout procedures. There may be insufficient information to apply such procedures or conduct simulations. These calculations can be complex and time-consuming, leaving little opportunity for extensive calculation before the start of operations (Vis & Roodbergen, 2011).

2.3. Cross docking Operation Processes

This literature review examines the key factors involved in cross-docking operations and highlights the challenges and opportunities for optimising the process.

2.3.1. Types of Cross docking Operations

There are four types of cross-docking operations: unloading, sorting, storing, and reloading (Ladier & Alpan, 2016). Unloading involves transferring goods from inbound trucks to a predetermined area. Sorting the goods involves a quality and quantity check on the goods before the goods are divided and transported to either storage or an outbound truck. Storage of goods takes place if the outgoing truck has yet to arrive. Although not all goods are stored, only those waiting on an outgoing truck. Reloading involves transferring goods from the staging area to outbound trucks. Cross-docking operations require effective coordination and communication between suppliers, manufacturers, retailers, and in-house staff (Ladier & Alpan, 2016).

2.3.2. Factors Affecting Cross-docking Operations Performance

Cross-docking operations face several challenges that can impact the efficiency and effectiveness of the process. One of the most significant challenges is coordinating and communicating between suppliers, manufacturers, and retailers (Ladier & Alpan, 2016). If stakeholders do not communicate effectively, it can cause delays and errors in the process (Ladier & Alpan, 2016). The arrival times of the trucks affect the planning and the process. If trucks have fixed schedules, it is crucial to consider their arrival in the planning horizon (Ladier & Alpan, 2016). On the other hand, if trucks arrive without a fixed schedule, it is assumed that all the trucks are available from the beginning of the planning horizon (time 0) and can be processed at any time. This logic applies to both inbound and outbound trucks (Ladier & Alpan, 2016).

The inventory level is a factor that will affect the operations in a cross-docking facility, given that reducing inventory is a crucial objective of cross-docking. Therefore, it is essential to track indicators of inventory levels, such as the total or maximum number of goods stored over the planning horizon (Boysen & Fliedner, 2010). The total travel distance of the goods is a factor that can affect the operations performance of the CD. Total travel time can provide insight, as longer transportation routes will increase the time required for the worker's operation (Ladier & Alpan, 2016). Minimizing the travel distance can result in clustering the loading and unloading area, potentially causing congestion, and hindering the process efficiency. It is challenging to measure congestion because there needs to be clear metrics to determine the performance impact (Ladier & Alpan, 2016). The total product stay time is also a factor that affects the operation's performance. When maximizing the goods turnover, tracking the overall time spent by all products within the CD is appropriate as a significant indicator when measuring operational performance (Ladier & Alpan, 2016). One possible performance indicator is the number of touches, which refers to the number of times a pallet is moved from one location to another. If a pallet is moved directly from the inbound truck to the outbound truck, it is only touched once. However, if it is stored temporarily before being moved to the outbound truck, it is touched twice, once when it is moved from the inbound door to the storage area and a second time when it is moved from the storage area to the outbound truck (Ladier & Alpan, 2016). More complex processes may require the pallet to be touched three or more times, each adding to the required labour cost (Ladier & Alpan, 2016). Therefore, tracking the average or total number of touches can be a valuable way to evaluate operational performance.

2.3.3. Opportunities for Optimising Cross-docking Operations

Several opportunities exist for optimising cross-docking operations. One approach is to use technology such as warehouse management systems (WMS) to automate processes and improve visibility. WMS can provide real-time information on inventory levels, order status, and shipment tracking, which can improve coordination and communication between stakeholders (Torabizadeh et al., 2020).

Taking account of cross-docking and ideal truck routing schedules is a significant development in cross-docking optimisation. This strategy entails coordinating the physical flow of goods between upstream suppliers and downstream retailers in each inbound and outbound process (Lo & Chuang, 2023). Reducing energy use by optimising inbound dock doors is another opportunity to improve cross-docking operations. Forklift energy consumption can be significantly decreased, saving money by reducing the effort necessary for inbound docking operations (Stanković et al., 2022).

Simulation techniques are applied to replicate real-world scenarios in cross-docking scenarios. For instance, an event-based simulation can be designed to assess the flow of packages and the time it takes to sort them while considering different assignments for cross-docking operations (Kiani Mavi et al., 2020). Furthermore, simulations can be used to model different floor area layouts in a warehouse to determine the optimal cross-docking capacity and optimise efficiency (Kiani Mavi et al., 2020).

2.4. Material handling equipment

Logistic centres and warehouses use different types of material handling equipment (MHE) to handle the goods to achieve an effective throughput (Amjed & Harrison, 2013). Examples of MHE used in cross-docking include conveyor systems, pallet jacks, and forklifts (Hama Karim et al., 2022). The value added by material handling is greater than the additional costs, for example, the overnight delivery compared to the regular mail service. By using MHE to streamline the transfer of goods, cross-docking can significantly reduce warehousing and inventory costs, improve order fulfilment speed, and increase overall supply chain efficiency (Hama Karim et al., 2022).

2.4.1. Forklifts

Forklifts are the most common MHE in warehouses, distribution centres, and other industrial settings (Huang et al., 2021). They are mainly used for lifting and transporting heavy loads since their ability to manoeuvre in tight spaces makes them ideal for usage in logistical centres (Huang et al., 2021). The forklifts come in various sizes and designs; they have different lifting capacities and features that specify the forklift for different needs. Forklifts have evolved a lot since the first version in the early 20th century, with features such as electric power, advanced safety systems, and ergonomic designs that increase operator comfort and productivity. Today, forklifts are essential in many industries, enabling businesses to move and store goods more efficiently and effectively (Masis et al., 2022).

2.4.2. Material Handling Equipment Power Sources

There are several options to power sources for forklifts used as an MHE, such as internal combustion engines and electric batteries. The combustion engine is run by diesel or liquid petroleum gas (LPG). Electric batteries are run by lead-acid or lithium batteries (Amjed & Harrison, 2013). There are differences of opinion on which of the options is the most environmentally friendly, and debates on how to measure emissions and environmental impact of the different power sources. This is due to the need for a standardized industry test cycle and inconsistencies in defining system boundaries (Keshan et al., 2016).

Diesel

Forklifts powered by diesel are the most common forklift type. This is due to their durability and capability to handle heavy goods (Haghi et al., 2020). However, their future is in the hand of the governments that can adopt policies that encourage the replacement of diesel forklifts (Haghi et al., 2020). When considering environmental impact, it is shown that diesel forklifts have a lower impact on the environment than liquid petroleum gas forklifts. When considering the upstream process of fuel extraction and production (Fuc et al., 2016).

Liquid Petroleum Gas

LPG forklifts, also known as propane forklifts, are popular for material handling operations since they offer several advantages over other types of forklifts. One of the key benefits of LPG forklifts is their fuel efficiency (Raslavičius et al., 2014). However, there are discussions about how efficient LPG is compared to diesel (Fuc et al., 2016) means that the overall environmental impact of LPG is higher than diesel engines. LPG is a clean-burning fuel that can operate indoors without expensive exhaust ventilation systems (Raslavičius et al., 2014). Another advantage of LPG forklifts is their versatility. The LPG forklifts can handle a variety of loads. They can operate on various surfaces, making them ideal for use in different facilities, from warehouses and distribution centres to construction sites and outdoor storage yards. LPG forklifts are also known for their ease of operation and maintenance. They have simple fuelling procedures and require less maintenance than diesel or electric forklifts (Fuc et al., 2016).

Lithium Batteries

Lithium (Li-ion) batteries are the most efficient rechargeable batteries available today, with the highest energy-to-weight and energy-to-space ratios (Keshan et al., 2016). Their operation relies on the reversible insertion and extraction of ions between two porous electrodes separated by a non-conductive foil. An electrolyte solution containing Li-ions charges the electrodes and separator foil. The battery's performance is heavily influenced by the charge and discharge current, unlike lead acid, which can be charged at much higher current rates. When subjected to high discharge currents, Li-ion batteries can deliver high power levels quickly, with minimal efficiency changes (Keshan et al., 2016). When fully charged, Li-ion batteries can reach up to 4.20V per cell, which is higher than the voltage of a lead-acid battery cell. The amount of energy stored in a charging Li-ion battery depends on the difference in energy states of the intercalated Li-ion between the positive and negative electrodes of the cell (Keshan et al., 2016). According to authors Keshan et al. (2016), an important point to mention is that lead-acid batteries perform better in low temperatures than Li-ion batteries.

Lead-acid Batteries

Lead-acid batteries are the most common electric battery in forklifts worldwide (Keshan et al., 2016). The performance of lead-acid batteries is highly dependent on the current rate that the battery is charged and discharged. Higher current rates, when discharging, will decrease operating time. When charging, higher current rates will charge the battery faster but affect the battery's lifetime (Keshan et al., 2016). The charging properties of the lead-acid battery include constant voltage, constant current, and the pulse method. The pulse method indicates the currents sent to the battery while charging (Horkos et al., 2015). The conventional charging techniques, such as constant voltage and constant current, have limitations that contribute to electrolyte decomposition and high gas generation, leading to a decline in battery performance (Horkos et al., 2015). There are newer techniques for charging lead-acid batteries, such as charging to full capacity faster than usual and then keeping the battery open. This technique is called intermittent charging. Another technique is called Interrupted Charge Control (ICC), which is based on intermittent charging and has the same attributes. However, the ICC technique ensures that the battery gets a full charge return by using constant current in the charging process (Keshan et al., 2016.; Horkos et al., 2015)

2.4.3. Environmental Impact of Power Sources

Measurement differs based on the boundary, such as 'well-to-pump', 'well-to-wheel', 'outlet-to-battery', 'battery-to-wheel', or 'wheel-to-exhaust', which leads to varying results for each fuel type (McKinnon et al., 2015). For example, LPG has the highest energy efficiency at 89.3% and the lowest CO2 emissions. However, one study found that it uses six times more energy per operating cycle than electricity (McKinnon et al., 2015). McKinnon (2015) mentions that using Li-ion batteries in forklifts will have a smaller impact on the environment if the facilities use green energy. However, Johnson (2008) means that LPG have the same or even a smaller environmental footprint than electricity. The main issue is that there is no industry standard to the definition on system boundaries. The system boundaries refer to whether a comparison of emissions between two energy sources (such as diesel and Li-ion batteries) should only include emissions during operational use, or if emissions produced during the production, generation, operation, and disposal of these energy sources should also be considered (Amjed & Harrison, 2013).

Electrical batteries and the impact that they create on the environment is based on the outlet-to-battery and battery-to-wheel. Leading factors to the overall environmental impact are the extraction, production, and generation, of the metals used in the batteries (Johnson, 2008). Another factor is the disposal and/or after life of the batteries. Whether or not the battery can be recycled in an environmentally friendly way is a factor that also affects the overall impact of electric batteries on the environment (Lacey et al., 2013). When considering the operational aspect of a forklift, the electrical forklift has a lower environmental impact compared to a forklift with an internal combustion engine (Fuc et al., 2016).

2.4.4. Phase-in and Phase-out of Material Handling Equipment

Forklifts are a critical component of many warehouse operations, and their proper maintenance and replacement are essential for ensuring that they perform efficiently and effectively. The phase-in and phase-out of forklift fleets are important aspects of fleet management that can affect the productivity and cost-effectiveness of warehouse operations (Renteria Marquez, 2017).

One of the critical factors to consider when evaluating replacement options for forklifts is the equipment's lifespan. The lifespan of a forklift is determined by various factors, including the type of forklift, its usage, maintenance history, and the environmental impact (Renteria Marquez, 2017). Forklifts that have been well-maintained and have undergone regular maintenance checks may have a longer lifespan than those that have been poorly maintained (Renteria Marquez, 2017).

When it comes to phasing in new forklift equipment, it is essential to select the right equipment that meets the specific needs of the warehouse operation (Preston et al., 2020). Factors to consider when selecting new forklift equipment include the type of products being handled, the size and layout of the warehouse, the availability of trained operators, and the environmental impact. It is also important to consider the cost-effectiveness of different equipment options, considering the purchase price, maintenance costs, and expected lifespan of the equipment (Preston et al., 2020).

Phasing out old forklift equipment involves retiring equipment that are no longer cost-effective or efficient (Xue et al., 2022). When retiring forklift equipment, factors that should be considered are the equipment's age, performance history, maintenance costs, and the availability of replacement parts. Once old equipment has been retired, it is essential to dispose of it in an environmentally responsible manner (Xue et al., 2022).

2.4.5. Material Handling Equipment Maintenance and Servicing

Forklifts have scheduled maintenance frequently throughout its lifespan. This entails routine inspections, lubrication, and part replacement to avoid equipment breakdowns. Preventive maintenance can help to decrease downtime and increase the lifespan of forklifts (Suryoputro et al., 2019) They also discovered that forklift operator training courses could lower equipment damage and boost safety.

Thermal imaging and vibration analysis are two examples of predictive maintenance methods that can be used to spot probable equipment breakdowns before they happen. Vibration analysis can be helpful in forecasting forklift failures and lowering maintenance costs (Suryoputro et al., 2019).

Proper servicing of forklifts is just as crucial as upkeep. The hydraulic system should be routinely cleaned and inspected, and batteries should be handled and stored properly. The longevity of forklift batteries can be increased with good battery management, which includes monitoring and maintenance (Suryoputro et al., 2019).

3. **Methodology**

The methodology chapter will present the methods used to answer the research questions during the thesis. The methodology will present design selection, data collection, case study, and research quality. These sections give an idea to the readers of how the authors plan to execute the report. These methods are described further below. The research process can be divided into four main periods, with each period focusing on specific topics, as illustrated in Figure 3.1. These periods describe the overall process of the research, while the topics highlight the tasks performed during each period.

3.1. Research Strategy and Design

The research design used in this study will combine a single case study and a mixed-methods approach (Creswell, 2018; Yin, 2014), as seen in Figure 3.1. By utilising qualitative and quantitative methods, a comprehensive understanding of the current state at Company X, the advantages, and obstacles of becoming more sustainable, and the factors that influence the decision to create an optimal environment for introducing an all-electric forklift fleet (Creswell, 2018; Yin, 2014).

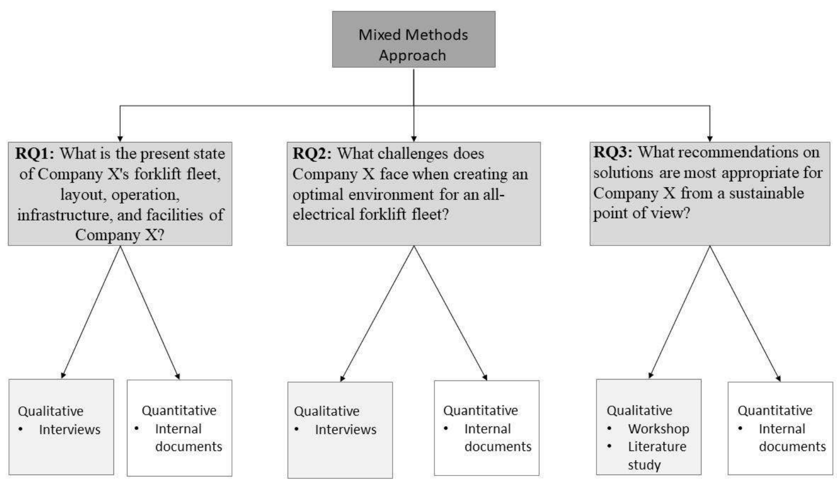


Figure 3.1: The research structure of this report, that used a mixed methods approach.

A single case study is a qualitative research design that involves an in-depth examination of a single unit of analysis (Yin, 2014). By delving into the unit of analysis, a single case study aims to provide a rich depiction of its features, characteristics, and contextual factors (Bell et al., 2022). This approach allows researchers to understand various phenomena in-depth, including individuals, programs, organisations, or any other topic of interest (Yin, 2014).

One of the main strengths of a single case study is its ability to offer a comprehensive understanding of the unit of analysis, along with the intricate relationships between variables and their contextual influences (Johnson & Onwuegbuzie, 2004). Through collecting qualitative data, researchers can gain valuable insights into the unique characteristics of the topic under investigation (Johnson & Onwuegbuzie, 2004). Despite its limitations, such as potential challenges related to overall applicability, a single case study can still significantly contribute to developing knowledge in a specific field (Creswell, 2018).

In contrast, the mixed methods approach involves collecting and analysing qualitative and quantitative data (Creswell, 2018). By using both forms of data, researchers can increase the robustness of their findings through triangulation, which increases the validity and reliability of the results (Creswell & Clark, 2007). This approach proves particularly beneficial when exploring complex research questions, as it enables a more comprehensive understanding of the topic by collecting data from multiple sources (Johnson & Onwuegbuzie, 2004).

By integrating qualitative and quantitative methods, a mixed methods research design allows researchers to explore a broader range of perspectives, use different data collection techniques and gain a more comprehensive understanding of the phenomenon under study (Creswell, 2018). The synthesis of qualitative and quantitative data enriches the analysis and provides a deeper insight into the intricate and complex nature of the research topic (Creswell & Clark, 2007).

In the first period of the research procedure, the authors will concentrate on understanding and describing the phenomenon. To gain a deeper understanding of the problem, the authors will engage in discussions with stakeholders from Company X. These discussions will help to understand the phenomenon thoroughly. The report will then describe the problem after this understanding has been achieved.

The second part of the research is about "Defining the Purpose and Research Questions". Here, the authors will establish the purpose of the research, which will be based on the challenges faced by company X. After establishing the purpose, the authors will formulate research questions that will guide them in achieving the research's objectives.

The third period of the research consists of two topics: "Literature Review" and "Collection and Analysis of Empirical Data". The authors will collect data from Company X during this period, including interviews and internal documents. In addition, they will conduct a detailed literature review of relevant sources relating to the report.

Finally, the authors will present the 'Result' in the fourth and last part of the research. This period involves summarising the data collected and the results of the literature study into the research's findings. The research questions posed in the research will be answered and discussed during this period. The different periods of the research process can be seen in Figure 3.2 below.

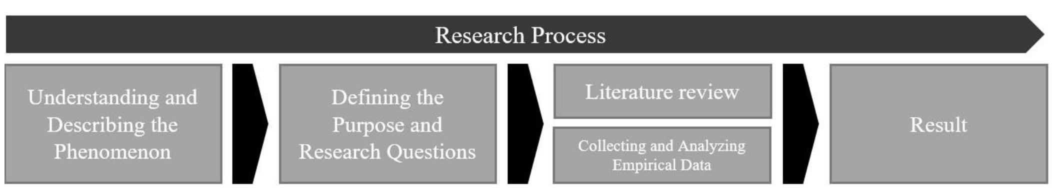


Figure 3.2: The research process

3.2. Data Collection

Data collection is a crucial step in the research process, and it is essential that it is conducted systematically. In this study, a multi-method approach will be used to collect data, including semi-structured interviews (Creswell, 2018), internal documents from the case company (Yin, 2014), a workshop, and a literature study.

3.2.1. Semi- structured Interviews

Bell et al. (2022) highlight that semi-structured interviews offer researchers a valuable method for exploring research questions flexibly and adaptively. This approach allows for a broader range of questions, promotes in-depth participant responses, and provides opportunities for further investigation based on the significance of the information shared. This study conducted seven semi-structured interviews with key stakeholders, including managers and team leaders seen in Table 1. The interviews were guided by 25 standard questions, ensuring a consistent foundation for data collection. However, the authors-maintained flexibility within the semi-structured format, adapting the sequencing and content of questions based on the interviewees' roles and responses.

Table 1: Interview The interviews that were conducted.

No.	Title	Location	Time spent (h)	Day (Date)
1	Development Manager	On-site	1,5	23/2/23
2	Facility Manager	On-site	1,5	23/2/23
3	Team Leader	On-site	1,5	6/3/23
4	Team Leader	On-site	1,5	6/3/23
5	Team Leader	On-site	1,5	6/3/23
6	Team Leader	On-site	1,5	8/3/23
7	Security Manager	On-site	1,5	8/3/23

The flexibility of the semi-structured interview approach allowed for a comprehensive exploration of the research topic, as noted by Bell et al. (2022). The broader frame of reference in the interview questions facilitated in-depth insights and perspectives from the participants, enabling a thorough examination of the case. Each interview lasted approximately one and a half hours, allowing ample time for detailed discussions and responses. The authors ensured that the interviews were conducted individually to create a comfortable and confidential environment for the participants to share their experiences and insights. This aspect of flexibility allows interviewers to go deeper into specific areas of interest or to seek clarification on certain points. It allows researchers to collect rich data, improving the results' overall quality (Bell et al., 2022).

To ensure accuracy and comprehensive analysis, the authors recorded, transcribed, and analysed the interviews. This process aimed to identify key themes, patterns, and interview information. By systematically analysing the interview data, the authors sought to gain a deep understanding of the case and uncover valuable insights (Creswell, 2018).

3.2.2. Internal Databases

During the study, the authors were granted access to several internal documents from Company X (from now on referred to as "databases"), which served as valuable sources of information. These documents included records of the number of hours the forklifts were used throughout 2022, the cost of renting forklifts in the same period, electricity consumption throughout 2022, and the facility's electricity delivery capacity. Additionally, the authors had access to drawings of the facilities. These internal documents provided crucial insights and data points for the analysis, enabling a comprehensive examination of relevant aspects within Company X.

The authors utilized qualitative and quantitative databases to manage and analyse the collected data, aligning with Yin's (2014) recommendations. Qualitative databases were employed to organize and manage data gathered through qualitative research methods like interviews, observations, and text analysis. These databases allowed for systematic storage and categorization of qualitative data, ensuring the capture and easy accessibility of essential information for analysis (Yin, 2014). On the other hand, quantitative databases were used to store and manage numerical data collected through surveys, questionnaires, experiments, and other quantitative research approaches. These databases provided a structured framework for organizing variables and data points and conducting analyses (Yin, 2014).

Adopting qualitative and quantitative databases facilitated data integrity, traceability, and reliability throughout the research process (Yin, 2014). The systematic documentation and organization of data supported comprehensive analysis and interpretation. The databases also provided a foundation for data-driven decision-making, hypothesis testing, and the generation of accurate and valid research outcomes. In the case of this study, internal databases played a crucial role in data collection from Company X, primarily utilizing documents and operational reports. This encompassed financial and operational data and information related to organisational structures and processes. Analysing this data allowed for a deeper understanding of Company X and its operations, aligning with the guidance provided by Yin (2014).

3.2.3. Workshop

To address the identified problems and develop an appropriate action plan, a half-day workshop was conducted with the participation of the management staff of Company X, the authors, a business developer, and a consultant. The workshop was a collaborative and interactive platform for in-depth discussions on the identified problems, drawing upon qualitative research, brainstorming, and problem-solving techniques.

Under the guidance of a host, the workshop created an inclusive and collaborative environment that encouraged active participation and guided discussions towards productive outcomes. The workshop structure aligned with the characteristics described by Skill Zone Ltd (2023) and combined elements of qualitative research, problem-solving and brainstorming techniques.

The discussions revolved around developing a strategic plan to address the challenges within Company X, considering the current situation, relevant literature, and the insights shared by the participants. During the session, the participants, including the authors and management staff, delved into a detailed examination of the identified problems. They engaged in collaborative problem-solving activities, generating innovative ideas and exploring potential solutions.

The workshop spanned approximately five hours and commenced with the authors presenting a summary of the current situation. Subsequently, the participants discussed the current situation, examined relevant literature, and deliberated on the best solutions for the company. The aim was to collectively analyse the identified problems, leverage the expertise and perspectives of the participants, and determine the next steps for the research.

3.2.4. Literature study

Conducting a broad literature review is an essential part of field research. It provides a foundation for the study, helps identify research gaps, informs the research design and methodology, and assists in data interpretation and analysis (Carol, 2018).

Carol (2018) highlights that a literature review is essential to qualitative field research and allows researchers to position their study within the existing scientific discourse. By reviewing relevant literature, researchers gain a deeper understanding of current knowledge, theories and concepts related to their research topic.

According to Carol (2018), a literature review allows researchers to identify gaps, inconsistencies, or controversies in the existing body of knowledge. This identification of gaps helps researchers formulate their study's unique contributions and ensures that their research addresses important issues in the field. It also helps to establish the theoretical basis of the research, align it with existing theories or propose new theoretical perspectives (Carol, 2018).

Moreover, a literature review supports the understanding and interpretation of the data. Carol (2018) highlights that a solid understanding of the existing literature enables researchers to understand their findings in a broader context. By comparing their findings with those of previous studies, researchers can identify consistencies, inconsistencies or alternative explanations, contributing to their interpretations' overall validity and reliability (Carol, 2018).

Finally, a literature review will be conducted to provide a theoretical context for the study. This will involve reviewing relevant literature, such as academic journals, books, and reports (Carol, 2018). The literature review will focus on key concepts and theories related to the research question and will be used to develop hypotheses and identify gaps in the existing literature (Carol, 2018). Some literature search words are Sustainable operations, Electrical Forklifts, Efficient Layout, and Sustainable Warehouses.

The literature is drawn from several databases, such as Chalmers Library, Google Scholar, and Research Gate. Overall, this multi-method approach will provide a comprehensive understanding of the case and help triangulate the data, increasing the study's validity and reliability (Creswell, 2018; Yin, 2014; Carol, 2018).

3.3. Case Company

The selected company, Company X, has established itself as a prominent player in the logistics industry since the beginning of the 20th century. Company X is a leading provider of transport and logistics services and has earned a reputation for delivering high-quality services to customers worldwide. Their broad range of services includes freight, warehousing, and transport solutions. With headquarters in Scandinavia, Company X has a global presence and employs around 10,000 people in more than 20 countries. Since the company has wished to be anonymous, the information presented about the company comes from internal documents and can't be referenced.

This case study focuses on highlighting how organisations are addressing the new needs of customers and stakeholders by making sustainability a top priority in their operations. Company X, driven by both the general push for businesses to adopt sustainable practices and the specific demands of its customers, is striving to respond effectively. One of its largest customers, a leading global OEM, has expressed a strong desire for its suppliers to adopt more sustainable practices. Company X has therefore initiated plans to replace its existing diesel forklifts with electric forklifts at its warehouse in Gothenburg, Sweden. This strategic shift will reduce Company X's environmental impact and improve its financial performance.

The supply chain of Company X, as illustrated in Figure 3.2 of the case study, starts at their CD facility. The primary function of this facility is to facilitate the transport of materials to customers' factories around the world, including places like Russia, Japan, and Brazil. Company X receives goods from customers' subcontractors, who send lorries with the goods to Company X's CD facility for unloading and sorting. After this process, the goods are loaded onto containers or lorries and transported to factories worldwide.

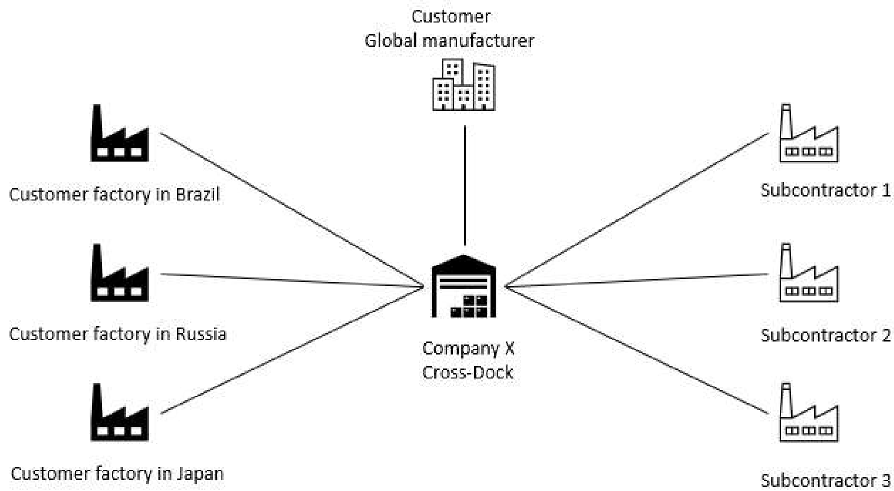


Figure 3.3: The supply chain that affects the CD where the case study is conducted.

3.4. Research Quality

Research quality is a fundamental aspect of any study, as it directly affects the credibility and reliability of the results. Several key factors must be considered to ensure research quality, including validity, reliability, and objectivity. This introduction will explore these factors and their importance in conducting a high-quality research study. It will also explain what was done to increase the research quality by the authors.

3.4.1. Validity

To increase the study's validity, the researchers employed the method of triangulation, which involved utilizing multiple data sources and perspectives (Saunders et al., 2016). By incorporating interviews, internal documents, literature, and insights from a workshop, the risk of bias was minimized, and a more comprehensive understanding of the topic was achieved (Saunders et al., 2016). This multifaceted approach ensured that the study correctly measured its intended objectives and enhanced the overall validity of the results. Moreover, the authors recognized the importance of selecting a specific target group and formulating precise and well-defined questions for interviews. By doing so, they ensured that the collected data was relevant and aligned with the research goals, further contributing to the study's validity (Björklund & Paulsson, 2014).

3.4.2. Reliability

Reliability, in this context, refers to the dependability and consistency of the measurement instruments used. This report used a systematic and rigorous data analysis method to ensure the reliability and consistency of the results (Björklund & Paulsson, 2014). The researchers aimed to adopt a sufficiently descriptive methodological framework to facilitate replication and yield comparable results, thus enhancing reliability. They also recognised the importance of integrating control questions within interviews and questionnaires, as these can contribute to increased reliability by assessing the consistency of responses (Björklund & Paulsson, 2014).

In addition, the study utilized triangulation techniques to support overall reliability (Saunders et al., 2016). Triangulation provided additional layers of corroboration, strengthening the trustworthiness of the findings. Triangulation involved using multiple sources of information, such as internal documents, interviews, literature, and workshop insights. By drawing from diverse sources, the researchers reduced the reliance on a single perspective and minimised bias, thereby enhancing the reliability of the study (Saunders et al., 2016).

The authors selected reliable sources for the literature study to enhance further reliability (Björklund & Paulsson, 2014), including reputable sources like the Chalmers Library. Using credible and trustworthy sources ensured the accuracy and reliability of the information cited throughout different sections of the report. By including empirical data as evidence to support various parts of the report, another reliability dimension was added (Björklund & Paulsson, 2014).

3.4.3. Objectivity

Objectivity in the study is crucial to minimise the influence of personal values and biases. The researchers acknowledged that personal values could impact the thesis, such as the interviewee's dependence on the interviewer (Björklund & Paulsson, 2014). To promote objectivity, providing justifications and specific details about the choices made during the research process is crucial, allowing readers to form their opinions about the study's results (Björklund & Paulsson, 2014). This approach increases the overall objectivity of the study.

Maintaining accuracy and impartiality when presenting the content from sources is also essential. The text should be free from factual errors, distorted selections of facts, and value-laden language, ensuring the information is objectively presented (Björklund & Paulsson, 2014). The researchers strived to avoid deliberately biased and subjective selections during the study.

In the case of interviews conducted for the study, privacy was ensured to uphold objectivity. The authors tried to establish independence from the company where the case study was carried out, eliminating any potential dependent positions that could compromise objectivity. By maintaining this independence, the authors could approach the study objectively and minimise any undue influence on the findings.

4. **Analysis and Findings**

This study is focused on evaluating the current state of Company X's forklift fleet, infrastructure, facilities, layout, and operational processes. Furthermore, the challenges that hinder the achievement of Company X's sustainability goals are identified. This analysis section presents the conclusions from internal documents and interviews.

4.1. Analysis of the Current Situation

This section will present an analysis of the current situation.

4.1.1. Current State of Company X

The objective of Company X is to operate in an environmentally friendly and efficient way to reduce their carbon emissions by 45% by 2030. Company X must do this to follow the requirement of their largest customer, the OEM, that state that the companies they work with must become more sustainable. While Company X has identified the need to become more sustainable, they have yet to make significant progress towards achieving this goal. However, the current state of Company X's sustainability efforts could be improved.

Company X is reactive in its approach to sustainability, focusing only on solving emergency problems that arise in its operations rather than proactively implementing sustainable practices. Currently, Company X is not actively working on improving its sustainability practices, except planning to electrify its entire forklift fleet. However, Company X is motivated to make a change, and is starting their sustainability journey with the electrification of their forklift fleet.

4.1.2. Forklifts

According to the information provided in the interview and internal documents, there are a total of 24 forklifts. Of these, nine are electric forklifts, and 15 are diesel forklifts. All the forklifts that companies have are leased from Linde. They also use a system from Linde called Linde Connets to keep track of the use of the forklifts. Leasing all nine electric forklifts from Linde costs about 90 000 SEK per month, and electricity costs about 2 SEK per kilowatt-hour see Table 4. Leasing all 15 diesel forklifts from Linde costs about 120 000 SEK per month, and diesel costs about 18 Swedish crowns per litre see Table 4. Electric forklifts are mainly used to load containers. They have a maximum capacity of four and a half tons. The batteries used in the electric buckets are lead-acid batteries. However, these forklifts require frequent recharging, typically 2-3 times per session, and occasionally need topping up with battery water. The average driving hours per year for each electric forklift is 33866 see Table 2.

Table 2: Electrical forklift driving hours per year.

No.	Forklift	Hours per year
1	C430	15136
2	C434	25433
3	C435	47880
4	C436	51824
5	C437	32393
6	C438	46434
7	C439	26906
8	C440	29749
9	C442	29038
Mean/year		33866

Diesel forklifts are used for loading and unloading trailers. They have a maximum capacity of five tons and may need refuelling once per session, which takes a maximum of 10 minutes. Each diesel forklift's average driving hours per year is 56130 see Table 3.

Table 3: Diesel forklift driving hours per year.

No.	Forklift	Hours per year
1	D401	59131
2	D402	38824
3	D403	47267
4	D404	55431
5	D405	52012
6	D406	54677
7	D407	64307
8	D408	67276
9	D409	60310
10	D410	47050
11	D411	62685
12	D412	48880
13	D413	62907
14	D414	51718
15	D415	69470
Mean/year		56130

Diesel forklifts have a higher maximum capacity than electric forklifts, but they require refuelling, which takes additional time. Although electric forklifts require frequent recharging, they can operate without any emissions, making them environmentally friendly. However, diesel forklifts are better suited for outdoor use due to their ability to handle rough terrain. The average number of driving hours per year for diesel forklifts is higher than that of electric forklifts. This could be because diesel forklifts are better suited for outdoor use and can operate longer without recharging.

Tabel 4: Forklift Cost (per month).

Type	Total Forklifts	Cost	Power Source	Power Source Cost
Electric forklift	9	90K SEK	Electricity	1,50 SEK/KWh
Diesel forklift	15	120K SEK	Diesel	17,5 SEK/L

4.1.3. Infrastructure and Facilities

In the CD area at Company X, there are three facilities utilized for the storage, unloading, and loading of trucks and containers. The primary facility for CD operations is the facility with gates seen in Figure 4.1. Additionally, there are two tents used for storing container goods. The CD facility is connected to the tents via roads.

The main facility features a total of 35 gates for loading and unloading, as well as for storage of pallets and goods. The CD facility is partly open, where the trucks drive into pockets. The items stored in the main facility are primarily for trucks and lorries, while the tents serve as storage for container goods and pallets. There are designated areas around the tents for the containers, making them easily accessible when needed.

The charging area for electric forklifts is inside the CD facility, next to a gate. The CD facility, including the current charging area, is secured up to 630 amps (A). The maximum recorded peak of electricity usage per day in the CD facility is 199,5A (see Appendix A). The battery water for the electrical forklifts is placed in the ART-N warehouse as seen in Figure 4.1.

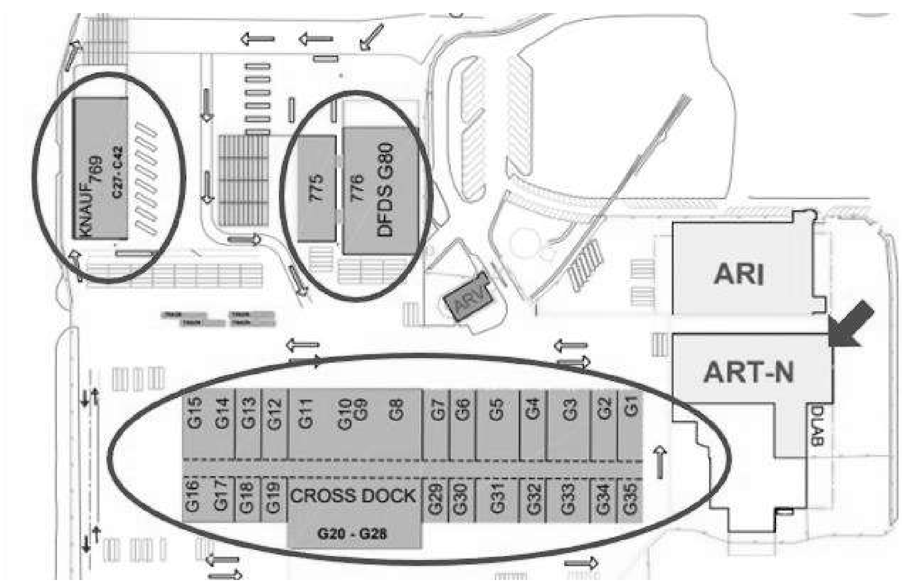


Figure 4.1: Drawing of the CD facilities where areas of relevance are highlighted.

4.1.4. Layout and Operational Processes

Out of the 35 gates, 22 is currently being used for loading and unloading operations, while the remaining gates are being used for storage purposes. The storage area is necessary because of the shortage of space, which has prompted the management to make use of the unused gates for this purpose. There are also allocated places in tents around the CD facility for the storage of container goods and pallets.

Of the 35 gates, 10 gates are dedicated to the unloading of trucks, while 12 gates are allocated for loading goods and pallets onto trucks. One of the gates is designated as a charging area for the electrical forklift batteries used in the CD area. This charging area ensures that the forklifts are always in operation and do not run out of power during the workday.

The ground of the CD area is marked with lines that indicate where goods and pallets should be placed, and the ceiling of the CD area has signs with SUFIX numbers that indicate the identification of each truck load. The forklift drivers unload the goods and pallets from the truck next to it, and then conduct quality and quantity control checks before moving them to their respective SUFIX number, where they are stored until the truck arrives to pick them up.

The storage is divided between the CD area and two additional tents, as shown in figure X. The tents are necessary because of the limited space available in the CD area. The diesel forklifts transport the goods and pallets from the trucks to the tents. The experienced forklift drivers have developed their own internal layout based on the CD areas demand and have trained new drivers accordingly. This internal layout helps the forklift drivers navigate the CD area efficiently, minimizing the risk of damage to the goods and pallets during transportation.

The planner plans the gates that the truck drivers should use when arriving to the terminal. The truck drivers have a responsibility to send a signal to the planner that the gate is available for the next truck. This signal is sent through GTMS system to the planner.

4.2. Challenges in becoming sustainable in Company X

Company X faces various challenges in creating an optimal environment for an all-electric truck fleet, making sustainability efforts more difficult. The challenges depend on MHE, infrastructure, facilities, layout, and operational processes. At present, these challenges represent barriers to achieving sustainability goals. The following sections describe these challenges in detail.

4.2.1. General challenges in Company X

First, Company X struggles to define the exact actions required to reduce carbon emissions by 45% by 2030. More clarity is needed to ensure effective planning and implementation of the necessary measures to transition to an all-electric forklift fleet. Secondly, the need for better-defined indicators to monitor and measure progress towards sustainability goals is a challenge. Without clear KPIs for sustainable development, it is difficult for Company X to assess its progress accurately. The lack of clarity makes it difficult to evaluate the effectiveness of current initiatives and adjust strategies accordingly. Thirdly, Company X faces the challenge of raising employee awareness of the importance of sustainability.

Finally, a short-term operational focus rather than a long-term strategic approach poses a major challenge. Company X tends to prioritize addressing immediate operational issues rather than taking a holistic, long-term sustainability perspective. This short-term thinking hinders the implementation of sustainable practices that can deliver lasting environmental benefits and economic success.

4.2.2. Challenges with the Forklift Fleet

One of the challenges is choosing the most sustainable power source for forklifts. The lack of standardized test cycles and inconsistencies in defining system boundaries further complicate this task. Another challenge is the poor battery capacity of electric forklifts used outdoors and in cold environments. Factors such as using electric forklifts outdoors, exposing the batteries to harsh conditions, charging them near open gates in the CD area, and neglecting battery maintenance by some drivers contribute to insufficient battery capacity. This directly affects Company X's ability to achieve its energy efficiency and CO2 emission reduction targets.

In addition, Company X faces challenges regarding forklift maintenance, especially for diesel forklifts used to transport goods and pallets. Frequent breakdowns, mainly caused by potholes on the road to the tents, pose operational risks and increase mechanical failures. Company X's outdoor activities and the deteriorating site condition further contribute to these breakdowns.

Furthermore, Company X is currently facing challenges specific to the forklift fleet. The breakdowns of the diesel forklifts disrupt operations, and their inability to be used inside containers adds to the operational challenges. From a sustainability point of view, it is crucial to address the environmental problems caused by diesel forklifts. Noise problems associated with diesel forklifts also affect the workplace environment. On the other hand, electric forklifts require frequent recharging, logistical problems for refilling battery water and reduced efficiency during winter, which affects productivity.

4.2.3. Challenges with Infrastructure and Facilities

Firstly, the CD facility faces several issues that directly affect the efficiency and productivity of its operations, which impacts the ability to electrify the forklift fleet. A major problem is that the charging area is located next to an open gate, making it impossible to maintain the warm environment necessary to charge the electric forklift batteries. As a result, the batteries lose capacity over time due to the lack of temperature control. The overall condition of the facility also contributes to the reduction of battery capacity, which negatively affects productivity and takes up valuable time. Furthermore, the open nature of the CD plant exposes operators to adverse weather conditions, making the working environment challenging and uncomfortable. This unfavourable situation can have a negative impact on operators' morale, enthusiasm, and overall work performance.

Additionally, the lack of cameras and sensors at the CD facility's gates makes it difficult for the planner to track availability at the gates accurately. This results in trucks waiting for long periods, causing delays, and potentially leading to traffic jams and slower operations. The lack of proper monitoring can also increase the risk of collisions between forklifts and create time-consuming situations at the gates.

In addition, the internal roads within the site suffer from poor conditions, including potholes and hazards. These road problems damage the forklifts and can also affect the goods being transported. Navigating around these hazards slows down the loading and unloading process, affecting operational efficiency. When bad roads damage the forklifts, they must be repaired, reducing the time forklifts are available.

In addition to these infrastructure and facility challenges, Company X faces sustainability-related obstacles. The deteriorating condition of the facility, characterized by leaking roofs and potholes, hinders the implementation of sustainability goals. Leaking roofs compromise the integrity of the building, lead to water damage, and increase maintenance needs. Potholes on internal roads pose safety risks and cause vehicle damage, negatively affecting operations. Contractual restrictions with the external property owner prevent the implementation of necessary changes.

Another sustainability challenge is the need for more space within the CD facility. This is due to goods and pallets taking up the gates, meaning container goods and pallets must be stored in tents outside the site. This lack of space disrupts logistics operations, creates bottlenecks, and hampers organization and efficiency. Moreover, it is a significant challenge to effectively balance the three key sustainability factors - social justice, economic efficiency, and environmental responsibility - efficiently.

4.2.4. Challenges with Layout and Operational Processes

The layout and operational tasks in the CD area play a crucial role in Company X's operations, including the unloading, loading and storage of goods and pallets. However, the current state of the layout and operations poses challenges that affect Company X's productivity, efficiency, and overall performance. One problem is that the battery water is located far from the charging area, which results in forklift operators having to actively think about filling the forklifts with battery water and moving around the premises to do so. Combined with charging in a cold environment, this leads to less-than-optimal forklift performance.

The visibility of road markings is another problem in the CD area. Thick layers of dirt cover the lines, making it difficult for forklift operators to navigate and identify designated areas for goods and pallets. In addition, the lines can be obscured by pallets and goods, leading to confusion and misplacement.

The experienced forklift operators in the CD area have developed their internal layouts to optimize workflow. There method may be more efficient for the moment. However, in the long run the workflow will be affected due to volatility in demand on the CD operations. Operators' layout changes can create risks, disrupt workflow, and waste time.

Misplaced goods and pallets occupy valuable areas, significantly affecting productivity and prolonging operations. The lack of planning for goods and pallet storage leads to bottlenecks and a lack of space for essential operations. In addition, transportation of goods and pallets from the CD area to off-site storage tents takes up time that could be better used for loading and unloading. Poor roads between the CD area and the tents pose risks of damage to goods and forklifts, leading to additional costs and time losses.

The lack of standardized operations also hinders Company X's ability to improve efficiency and consistently apply sustainable practices. Poor leadership in the CD area and insufficient commitment from other departments contribute to the lack of standardization.

Company X also needs help with misleading signage within the CD facility. Outdated or incorrect SUFFIX numbers on the signs can cause inefficiencies, errors, and disruptions to operations, hindering progress towards sustainability. Management deprioritisation and lack of monitoring contribute to the problem. Moreover, it is a collaborative effort between management, employees, and relevant stakeholders.

4.3. Cost and investment calculations

To assess the financial implications of the new electrical forklift fleet, an investment analysis is conducted. This analysis should compare the costs of changing to an all-electric fleet using Li-ion batteries and lead-acid batteries versus continuing with the hybrid forklift fleet. It should consider upfront costs for leasing Li-ion batteries, lead-acid batteries, and any necessary charging infrastructure upgrades for each alternative of batteries. The current forklift information, where costs are highlighted for the electrical and diesel forklift are shown in Table 5. For the current hybrid forklift fleet, the calculations present the current cost analysis see Table 6. Where no additional investment for the facility is necessary.

Table 5: Current Forklift Information

Power Source	Leasing Cost	Consumption rate	Drift Cost	Service cost	Total cost/Month	Total Cost/Year
Electrical	10K SEK	16 KWh	4K SEK	1K SEK	15K SEK	180K SEK
Diesel	8K SEK	3,5 L/h	10K SEK	2K SEK	20K SEK	240K SEK

Table 6: Current Forklift Fleet Cost

Number	Power Source	Cost/Month	Cost/Year
9	Electrical	135K SEK	1 610K SEK
15	Diesel	310K SEK	3 680K SEK
Total Cost			**5 290K SEK**

The tables below present the cost and investment calculations for a fully electric forklift fleet using lead-acid batteries see in Table 8. Implementing an all lead-acid battery forklift fleet requires investments in the facility and infrastructure at Company

X. Switching from a hybrid truck fleet to a fully electric truck fleet with lead-acid batteries comes with changed parameters for the cost and investments calculations. The leasing price for lead-acid during the phase-in period increases from 10 000 SEK in 2023 to 14 000 SEK in 2025 according to internal documents, when the forklifts are expected to be delivered to Company X. The general information about lead-acid battery forklift is shown in Table 7.

Table 7: Lead-acid battery information

Leasing Cost	Consumption rate	Drift Cost	Service cost	Total cost/Month	Total Cost/Year
14K SEK	16 KWh	4K SEK	1K SEK	19K SEK	228K SEK

Investment calculation for the facility at Company X starts with the construction work on the electrical control centre, construction work for battery charging, sockets, and loading stations seen in Table 8. These are required since the CD facility in its current state cannot provide an all-electrical forklift fleet with enough electricity. The battery stands and screen roof for battery rack and service station are an investment that is required for the batteries that are charging. It is also important that the environment while charging is heated and controlled, therefore there is a need for a screen roof. When implementing a forklift fleet with lead-acid batteries there are an expected reduction in productivity. This is because lead-acid batteries do not have the same production capacity as the hybrid forklift fleet. This fact is based in the data, that show that the efficiency of the lead-acid batteries that Company X have in their current state and the loss of battery capacity that has been noted on Linde Connect.

Table 8: Investment calculation for implementation of lead-acid battery forklift fleet

Facility Investment Required for Implementing Lead-acid Battery	Cost
Construction work on the electrical control center including materials	400K SEK
Excavation work for electrical substation	200K SEK
Construction work for sockets/loading stations	350K SEK
Construction work for battery charging	100K SEK
Battery stand	350K SEK
Screen roof for battery rack and service station	400K SEK
Investment Cost	**4 200K SEK**
Reduced productivity	2 200K SEK
Total Investment Cost	**6 400K SEK**

With a forklift fleet of 24 forklifts operating in the CD area, the total leasing cost of the entire forklift fleet is calculated and shown in Table 9.

Table 9: The total leasing cost for the entire all electrical forklift fleet using lead-acid batteries.

Number	Power Source	Cost/Month	Cost/Year
24	Electrical	336K SEK	4 032K SEK
Total Cost			**4 032K SEK**

The tables below present the cost and investment calculations for a fully electric forklift fleet using Li-ion batteries. The Li-ion batteries have a higher leasing cost than lead-acid forklifts. Although, the remaining parameters are identical to the lead-acid battery forklifts as is shown in Table 10.

Table 10: Li-ion battery information

Leasing Cost	Consumption rate	Drift Cost	Service cost	Total cost/Month	Total Cost/Year
18K SEK	16 KWh	4K SEK	1K SEK	23K SEK	276K SEK

The implementation of an all-electrical forklift fleet using Li-ion batteries also requires investments in the facility of Company X seen in Table 11. However, by introducing a fleet of forklifts with Li-ion batteries, Company X has no reduction in productivity, as the Li-ion batteries can maintain the same productivity as the hybrid forklift fleet. In comparison to the lead-acid batteries, Li-ion batteries also do not need a battery stand as the battery is a fixed component of the forklift. A larger investment is required for the construction work on the electrical control centre for Li-ion batteries, since each forklift requires 32 amps to charge, in comparison to the lead-acid batteries that only require 16 amps to charge.

Table 11: Investment calculation for implementation of Li-ion battery forklift fleet

Facility Investment Required for Implementing Lithium Battery	Cost
Construction work on the electrical control centre including materials	1 400K SEK
Excavation work for electrical substation	200K SEK
Construction work for sockets/loading stations	450K SEK
Screen roof for service station	450K SEK
Total Investment Cost	**2 500K SEK**

With a forklift fleet of 24 forklifts operating in the CD area, the total leasing cost of the entire forklift fleet using Li-ion batteries is calculated and shown in Table 12.

Table 12: The total leasing cost for the entire all electrical forklift fleet using Li-ion batteries.

Number	Power Source	Cost/Month	Cost/Year
24	Electrical	432K SEK	5 184K SEK
Total Cost			**5 184K SEK**

The cost and investment calculations show that Li-ion batteries as a power source would be less costly for Company X to implement. The lead-acid batteries would have cost 4 032K SEK in yearly leasing costs and have an investment cost of 4 200K SEK. However, an additional cost emerges with the lead-acid option, reduced capacity, which will cost Company X 2 200K SEK, leading to a total investment cost of 6 400K SEK. The Li-ion batteries will have a yearly leasing cost of 5 184K SEK, higher than the lead-acid yearly leasing cost. However, the total investment cost of implementing a fully electrical forklift fleet using Li-ion batteries as a power source would cost Company X 2 500K SEK, which is 3 900K SEK less expensive than the lead-acid option. The costs provided in the cost and investment calculations was provided by Company X. In addition, the cost and investment calculations are based on current cost level of the elements. Changes in, electricity prices, SEK exchange rates, interests, battery mineral and chemicals prices will affect the investment and cost calculations of the electrified forklift fleet.

5. **Results**

The results chapter presents recommended solutions for Company X to improve sustainability. By addressing research question 3 on suitable solutions from a sustainability perspective, the results aim to guide Company X in identifying strategies that align with its sustainability goals.

5.1. Recommendations for Company X from a Sustainable Point of View

This section presents recommended solutions to help Company X become more sustainable. To answer research question 3: "Which solutions are most suitable for Company X from a sustainable point of view?". By answering RQ3, Company X have the opportunity to identify strategies that are in line with Company X's sustainability goals. Recommendation 1 focuses on making sustainability goals visible and promoting a culture were sustainability guides Company X's activities. Recommendation 2 suggests transitioning the forklift fleet from a hybrid fleet to a fully electric fleet to reduce carbon emissions and improve efficiency. Recommendation 3 deals with improvements to infrastructure and facilities, while recommendation 4 proposes improvements to layout and operational processes in the CD area. By implementing these solutions, Company X can prioritise sustainability, reduce its environmental impact and establish itself as a socially responsible company.

5.1.1. Creating a Sustainability Strategy

Firstly, Company X needs to define clear and specific actions required to reduce carbon emissions by 45% by 2030. This involves developing a consistent sustainability strategy with well-defined targets. Company X can effectively plan and implement actions to transition to a fully electric forklift fleet by setting clear targets. Ali et al. (2023) ranked the best activities to become more sustainable, which include green operations, implementing green policies and strategies, training employees on green practices, introducing green transport, green work environment and culture, conducting environmental monitoring and control, and developing green buildings and infrastructure. The sustainable performance measures that Company X can use, mentioned as the most important indicator by Ali et al. (2023), is the reduction of energy consumption costs due to implementing sustainable and environmentally friendly activities. The next best performance measure that Company X may have to consider is the reduction of toxic emissions.

Secondly, establishing defined and key performance indicators (KPIs) is crucial for monitoring and measuring progress towards sustainability goals. Clear KPIs will enable Company X to assess the effectiveness of current initiatives and adjust strategies accordingly. This will provide valuable insights into Company X's progress and guide decision-making processes. Based on the measures mentioned above, the following four KPIs can be used:

1. Total energy savings: Measure the total cost savings achieved by implementing sustainable and environmentally friendly activities.

2. Energy cost per touched unit: Calculate the energy cost per touched unit to track improvements in energy efficiency.
3. Total reduction in toxic emissions: Measure the reduction resulting from sustainable practices.
4. Toxic emissions per touched unit: Calculate the number of toxic emissions released per touched unit to track improvements in environmental impact.

Thirdly, raising employee awareness and promoting a culture of sustainability is essential (Ali et al., 2023). Ali et al. (2023) suggest that employee training programmes focusing on energy-efficient practices and sustainable operations will help promote a sustainability-oriented mindset. Company X can create a workforce that actively contributes to sustainable practices by providing regular training and enhancing employees' understanding of sustainability goals.

Lastly, Company X must shift from a short-term operational focus to a long-term strategic approach. This entails prioritizing and incorporating sustainability considerations into Company X's overarching strategy. By adopting sustainable best practices, such as those mentioned in the literature review 2.2.5, Company X can ensure long-term environmental benefits and economic success.

5.1.2. New Electrical Forklift Fleet

Firstly, Company X should develop a comprehensive fleet conversion plan outlining the step-by-step process of phasing-out the existing forklift fleet, and phasing-in an all-electric forklift fleet (Preston et al., 2020). Factors to consider when phasing-in new forklift equipment include the type of products being handled, the size and layout of the warehouse, the environmental impact, number of electric forklifts required, and prioritization based on usage frequency. It is also important to consider the cost effectiveness of different equipment options, considering the purchase price, maintenance costs and the expected lifespan of the equipment, according to Preston et al. (2020). When phasing-out the old forklift equipment, factors such as the equipment's age, performance history, maintenance costs, and the disposal of it in an environmentally responsible manner, needs to be taken into consideration.

To ensure optimal performance and environmental friendliness, Company X should carefully select between lead-acid batteries and Li-ion batteries as their power source for the new forklift fleet. Lead-acid and Li-ion batteries are both the most widely used types of batteries for stationary operational tasks voltage (Horkos et al., 2015). There are benefits and drawbacks for each battery type. The performance of lead-acid batteries is highly dependent on the current rate of the charging and discharging of the battery. When discharging at a high current rate, the lead-acid battery will decrease in operation time voltage (Horkos et al., 2015). The Li-ion battery is less affected by the current rate at discharge, they can undergo faster current rates and still maintain the same operation time. The conventional charging techniques, such as constant voltage and constant current, have limitations that contribute to electrolyte decomposition and high gas generation, leading to a decline in battery performance for lead-acid batteries voltage (Horkos et al., 2015). Li-ion batteries can reach up to 4.20 voltage per cell, making the Li-ion batteries more resistant to higher voltage (Horkos et al., 2015). However, there are newer techniques for charging the lead-acid batteries that allow higher rates of voltage when charging and maintaining the same battery performance.

This technique is called Interrupted Charge Control (ICC), the ICC technique ensures that the battery gets a full charge return by using constant current in the charging process (Keshan et al., 2016.; Horkos et al., 2015).

The charging procedure varies between batteries, Li-ion batteries get charged by plugging the forklift to a charging station and takes between 1-2 hours to get them fully charged (Keshan et al., 2016). Which means that the Li-ion battery forklift cannot be used while it is charging. Unlike the lead-acid battery, to charge the lead-acid battery the operator takes the battery out of the truck and places it on a charging stand, ideally there should be another lead-acid battery fully charged already (Keshan et al., 2016). This means that Company X gets no standing time when the lead-acid battery is charging. After a full charge of the battery, operators must top up the battery with battery water for lead-acid batteries. This is not a process that the Li-ion battery needs to do after a full charge. Another difference between the batteries is that Li-ion batteries can be fully discharged without affecting battery performance, unlike a lead-acid battery where a full discharge of the battery affects the performance of the battery voltage (Horkos et al., 2015).

In summary, the leasing cost of the lead-acid batterie forklift fleet is less than the leasing cost for the Li-ion batteries, by 1.37 MSEK. However, the lead-acid forklift fleet requires investments in the infrastructure and facilities at Company X that will cost 6.4 MSEK, while the option with Li-ion forklift fleet requires investments that will cost 2.5 MSEK. The difference in investments between lead-acid batteries and Li-ion batteries are 3.9 MSEK.

5.1.3. Improving the Infrastructure and Facilities

Firstly, it is crucial to address the issues within the CD facility that directly impact the efficiency and productivity of operations, particularly the charging area for electric forklifts. By relocating the charging area to an enclosed space, separate from the open gates, Company X can maintain a warm environment necessary for optimal battery charging. This will prevent capacity loss due to temperature variations and improve forklift fleet performance and productivity (Keshan et al., 2016).

Improvements to internal roads within the site are essential to eliminate hazards and potholes. Repairing and maintaining the roads will protect forklifts and goods from damage and contribute to smoother and faster loading and unloading operations. This will enhance operational efficiency and reduce time-consuming delays caused by navigating around road hazards (Richards, 2022).

Furthermore, addressing the deteriorating condition of the facility is crucial for sustainability. Repairing leaking roofs and potholes will ensure a safe and functional working environment, while preserving the integrity of the building. This will help prevent water damage to the products, reduce maintenance needs, and create a more sustainable infrastructure for warehouse operations. Regarding improving the building, Richards (2022) says that the best practices for sustainable warehouse management are introducing energy-efficient lighting, installing motion sensors and timers, and utilising natural light through skylights to help minimise lighting costs. These are factors that Company X should keep in mind when renovating their facilities or constructing a new building.

Another aspect to consider is additional space within the CD facility to accommodate the goods and pallets stored in external tents. Expanding the facility or optimising storage areas will reduce logistical disruptions, bottlenecks, and inefficiencies. This will enhance the organisation, operations, and support sustainability goals by improving overall resource utilisation.

5.1.4. Improving the Layout and Operational Processes

One challenge is the location of the battery water, which leads to drivers needing to remember to refill the forklifts. To overcome this, a dedicated area for battery water should be established near the charging area. This will ensure easy access and remind forklift drivers to refill the forklifts, optimising their performance. The visibility of road markings within the CD area is another challenge. Clear road markings will facilitate smoother operations and reduce errors. Cleaning the lines regularly and implementing measures to prevent lines from obscuring by goods and pallets will improve navigation and prevent confusion or misplacement.

The internal layout developed by experienced forklift operators should be reviewed and optimised to enhance operational efficiency and standardise workflow (Horta et al., 2016). The layout should be designed based on efficiency and ease of navigation, considering factors such as the flow of goods, proximity to storage areas, and minimising risks of damage. New operators should be trained to follow the optimised layout to ensure consistency and maximise operational efficiency. The CD could utilise category-based layouts to introduce more flexibility to the layout. Category-based layouts involve using a limited number of situations based on the facility's activity level (Horta et al., 2016). For example, busy, average, and quiet days each have a different fixed layout for each situation. In determining the appropriate layouts, a forecast is made for the expected demand in the facility, which dictates the layout's decision. An analysis of different factors that need to be considered within the forecast is conducted (Horta et al., 2016). Category-based layouts offer added flexibility compared to fixed layouts, but they require employees to adapt to different layouts. If adapting to different layouts is a concern, only a few categories should be used (Vis & Roodbergen, 2011).

Furthermore, standardising operations within the CD area is vital to enhance efficiency and consistency. Clear guidelines, coordinated decision-making, and commitment from different departments should be established to ensure standardised processes. This will contribute to operations, effective resource utilisation, and improved sustainability practices. Addressing the issue of misleading signage within the CD facility is crucial. Regularly maintaining and monitoring signage, ensuring correct and up-to-date information, will prevent errors and disruptions. Prioritising proper signage as part of the facility's maintenance plan will enhance operational efficiency and support sustainability objective.

6. **Discussion**

This chapter focuses on discussing the strengths and weaknesses of the study. It analyses the company's industry position and sustainability journey and evaluates how well the data was collected through interviews, internal document analysis, workshops, and literature review.

6.1. Strengths and weaknesses of the study

The company's position at the forefront of the industry raises an essential question about the need for forward-thinking in its sustainability journey. Although the logistics industry is known for its slow adjustment to change, there appears to be a significant gap compared to other sectors. The case study highlights the importance of customer pressure in driving sustainability initiatives, which can trigger the logistics industry to evolve and catch up.

The methodology used in this study included a range of data collection approaches, including interviews, analysis of internal documents, workshops, and a literature review. Each method had its strengths and weaknesses and contributed to the overall direction of the study.

Semi-structured interviews were conducted, which allowed the authors to have a fluid dialogue with the participants. This approach proved beneficial as follow-up questions could be asked, leading to a deeper understanding of Company X. However, a potential area for improvement of this method was the risk that essential questions could have been answered. Furthermore, the interview questions were standardised for all interviewees, without adaptation based on individual interviewers.

The analysis of internal documents provided data on Company X's operations and offered timely information that formed an essential part of the analysis of the results. However, some of the data proved challenging to understand and required guidance from Company X to realise their importance fully.

A workshop was conducted, which played an essential role in shaping the results and in answering research question 3. The workshop provided a holistic view of the problem and facilitated the development of possible recommendations. However, a limitation of the workshop was that it included only management personnel. If the forklift drivers had been included, they could have provided valuable insights into operational aspects and given better answers to some operational questions.

In addition, an extensive literature review was carried out, including a range of publications relevant to the research subject. This approach helped to provide a solid foundation for the study. The strength of the literature review lies in the different perspectives and insights offered by different sources. The literature identified critical areas for improvement that aligned with the issues observed in Company X, such as the need for better temperature control in facilities to increase sustainability in economic, social, and environmental aspects. The literature also highlighted best practices in other organisations, which provided valuable benchmarks.

Although most of the literature could be related to the company's current situation, there were cases where the authors had to draw their conclusions, which can be considered a weakness of the literature. For example, the literature provided different recommendations and measures to determine the best energy source for sustainability, which made it necessary for the authors to rely on investment calculations and consider the company's specific operating environment. Another area where the literature needed improvement was suggesting appropriate key performance indicators (KPIs) to measure performance. The authors, therefore, had to develop their recommendations for the company. However, it would have been beneficial to have literature that suggests KPIs that have proven effective in other companies.

Another limitation of the literature study was the need for case studies in environments similar to the case company's environment, which was electricity certification in a cross-dock for increased sustainability. Most of the available case studies related to "standard" warehouses, and it would have been beneficial to have more relevant cases to benchmark.

The study aimed to answer the research questions using these different data collection methods. The strengths of each method complemented each other, while the weaknesses highlighted areas for improvement and potential limitations. Combining these methods enabled a more robust analysis and provided a more well-balanced perspective on the research topic.

7. **Conclusion and Future Research**

In conclusion, this thesis investigates the necessary steps to create an optimal environment for introducing an all-electric forklift fleet within Company X. The research focused on various areas, including the forklift fleet, layout, operational processes, facility, and infrastructure. The primary objectives were to understand the current state of these areas, identify the challenges associated with the transition from diesel to electric forklifts and provide sustainable recommendations for Company X to meet stakeholder requirements.

7.1. Conclusions from the Perspective of the Study and Company X

The methodology employed in this study incorporated multiple data collection techniques, including interviews, internal document analysis, workshops, and a literature review. Each method had strengths and weaknesses, contributing to a comprehensive understanding of the research questions. Semi-structured interviews facilitated in-depth dialogues, while internal document analysis provided timely and crucial information. The workshop offered a holistic view of the problem, although the lack of forklift drivers could have improved operational insights. The literature review, with its diverse perspectives, provided a solid foundation for the study.

The following questions have been answered in chapter four, and discussed throughout the report:

RQ1: What is the present state of Company X's forklift fleet, layout, operation, infrastructure, and facilities of Company X?

RQ2: What challenges does Company X face when creating an optimal environment for an all-electrical forklift fleet?

RQ3: What recommendations on solutions are most appropriate for Company X from a sustainable point of view?

The findings of this thesis will provide Company X with insights into its current challenges and recommendations for achieving its sustainability goals.
The study conducts an in-depth literature review on sustainable warehouse management, cross-docking, operational processes, and material handling equipment. This in-depth exploration has provided the writers of this report with a comprehensive understanding of the best practices in these areas. Drawing from this knowledge, the thesis offers Company X well-informed suggestions to improve its sustainability practices and operational efficiency.

By leveraging the research findings and incorporating the recommended practices, Company X can enhance its sustainability efforts and make significant strides towards a more environmentally conscious operation. The suggestions are based on industry best practices and aim to provide Company X with the most effective strategies to achieve its sustainability objectives.

7.2. Conclusions from an industrial perspective

Taking an industry-level perspective, the results of this thesis contribute to a broader understanding of sustainable practices in the logistics industry. By examining the challenges and providing recommendations for Company X, this research offers valuable insights that may inspire other companies in the industry. The in-depth study of sustainable warehouse management, cross-docking, operational processes, and material handling equipment provides a comprehensive understanding of best practices in these areas. It serves as a valuable resource for business professionals.

Implementing the recommendations outlined in this thesis requires a collective effort from all stakeholders in the industry. Companies must be willing to invest the necessary resources, including energy, expertise, and financial support, to drive the transformation towards sustainability. Adopting a holistic approach is crucial, as sustainability initiatives must be integrated into all aspects of the business.

Although the implementation process may present challenges, companies can utilise the research-based recommendations in this report to achieve their sustainability goals. Recognising that each company may face unique challenges and hurdles, such as a lack of expertise or financial constraints, is essential. However, by following the suggested strategies and utilising industry best practices, companies can significantly reduce emissions and improve their overall competitiveness.

This study seeks to ultimately contribute to the industry-wide transition to sustainable material handling practices. By spreading the knowledge and insights from this study, we hope that companies across the industry will be empowered to embrace sustainability and work towards a more environmentally conscious future.

7.3. Future Research

Researchers can contribute to the continued improvement and development of electric forklifts by investigating new technologies and their potential applications. Future research directions include exploring advances in electric forklifts, charging infrastructure and battery technology. This research would examine how these advances can effectively address the challenges identified in the thesis and optimise the introduction of all-electric forklifts.

In addition, researchers could investigate how to integrate all-electric forklifts with renewable energy sources, such as solar or wind power. This research would examine the feasibility, benefits and challenges associated with integrating renewable energy to power forklifts, thereby increasing the sustainability and environmental impact of the fleet. By evaluating the potential synergies between electric forklifts and renewable energy, researchers can contribute to developing sustainable material handling practices.

Additionally, it would be valuable to conduct long-term studies to evaluate the performance, reliability, and durability of all-electric forklifts. This research would include an assessment of maintenance needs, battery life and overall performance over more extended periods. By gaining insight into electric forklifts' long-term viability and cost-effectiveness, researchers can inform companies considering adopting this technology about their decision-making processes.

Another potential future research approach is performing a benchmarking analysis between companies that have successfully introduced all-electric forklifts and those that have not. This research identifies the key factors and strategies contributing to a successful transition. By analysing these companies' experiences, the researchers can discover valuable insights and best practices to help other organisations navigate the process more effectively. This comparative analysis would shed light on critical success factors, challenges to be overcome and lessons learned, providing practical guidance for companies looking to introduce all-electric forklifts.

References

Ali, S. S., Kaur, R., & Khan, S. (2023). Evaluating sustainability initiatives in warehouse for measuring sustainability performance: an emerging economy perspective. *Annals of Operations Research*, *324*(1–2), 461-500. https://doi.org/10.1007/s10479-021-04454-w

Amjed, T. W., & Harrison, N. J. (2013). A Model for sustainable warehousing: from theory to best practices. In Proceedings of the International Decision Sciences Institute and Asia Pacific DSI Conference (pp. 1-28).

Bartolini, M., Bottani, E., & Grosse, E. (2019). Green warehousing: Systematic literature review and bibliometric analysis. *Journal of Cleaner Production, 226*, 242-258.

Bell, E., Harley, B., & Bryman, A. (2022). *Business research methods*, Sixth edition, Oxford: Oxford University Press

Björklund, M. & Paulsson, U. (2014). *Academic Papers and Theses: To Write and Present and to Act as an Opponent*. 1.st ed. Lund: Studentlitteratur.

Boverket. (2023). Voluntary environmental certification. https://www.boverket.se/en/start/building-in-sweden/developer/rfq-documentation/climate-declaration/environmental-certification/

Boysen, N., & Fliedner, M. (2010). Cross dock scheduling: Classification, literature review and research agenda. *Omega, 38*(6), 413–422. https://doi.org/10.1016/j.omega.2009.10.008

Bailey, C. (2018). *A Guide to Qualitative Field Research.* SAGE Publications, Inc. https://doi.org/10.4135/9781071909614

Creswell, J. W. (2018). *Research design: qualitative, quantitative, and mixed methods approaches*. Sage publications.

Creswell, J. W., & Clark, V. L. P. (2007). *Designing and conducting mixed methods research*. Sage Publications.

De Bruyn, S., Jongsma, C., Kampman, B., Görlach, B., & Thie, J.-E. (2020). Energy-intensive industries Challenges and opportunities in energy transition. Policy Department for Economic, Scientific and Quality of Life Policies Directorate-General for Internal Policies. https://www.europarl.europa.eu/RegData/etudes/STUD/2020/652717/IPOL_STU(2020)652717_EN.pdf

Department of Energy and Climate Change (DECC) (2013) *Energy Consumption in the UK: Service sector data tables*, 2013 Update, HM Government, UK

Deloitte Insights. (2020). Electrification in industrials. https://www2.deloitte.com/us/en/insights/industry/power-and-utilities/electrification-in-industrials.html

Fuc, P, Kurczewski, P, Ziolkowski, A, Lewandowska, A, Nowak, E, & Selech, J. (2016). An environmental life cycle assessment of forklift operation: a well-to-wheel analysis. *International Journal of Life Cycle Assessment, 21*(10), 1438-1451. https://doi.org/10.1007/s11367-016-1104-y

Richards, G. (2022). *Warehouse Management: The Definitive Guide to Improving Efficiency and Minimizing Costs in the Modern Warehouse*: Vol. Fourth edition. Kogan Page.

Haghi, E., Shamsi, H., Dimitrov, S., Fowler, M., & Raahemifar, K. (2020). Assessing the potential of fuel cell-powered and battery-powered forklifts for reducing GHG emissions using clean surplus power; a game theory approach. *International Journal of Hydrogen Energy, 45*(59), 34532-34544.

Hama Kareem, J. A., Mohammed, B. I., & Abdulwahab, S. A. (2022). Optimal Materials Handling Equipment and Defective Product Reduction Skills in Enhance Overall Production Efficiency. *SAGE Open, 12*(4), 1–16. https://doi.org/10.1177/21582440221128769

Horkos, P. G., Yammine, E., & Karami, N. (2015). Review on different charging techniques of lead-acid batteries. In 2015 Third International Conference on Technological Advances in Electrical, Electronics and Computer Engineering (TAEECE) (pp. 27-32). IEEE.

Horta, M., Coelho, F., & Relvas, S. (2016). Layout design modelling for a real world just-in-time warehouse. *Computers & Industrial Engineering, 101*, 1–9. https://doi.org/10.1016/j.cie.2016.08.013

Huang, Y. Y., Horvath, L., & Böröcz, P. (2021). Measurement and analysis of industrial forklifts vibration levels for unit load testing purposes. Applied Sciences (Switzerland), 11(7). https://doi.org/10.3390/app11072901

IBM. (2023). *What is sustainability in business?* IBM. Www.ibm.com. https://www.ibm.com/topics/business-sustainability

IEA. (2022). Energy Efficiency, IEA, Paris https://www.iea.org/reports/energy-efficiency, License: CC BY 4.0

Johnson, E. (2008). Disagreement over carbon footprints: A comparison of electric and LPG forklifts. Energy Policy, 36(4), 1569-1573–1573. https://doi.org/10.1016/j.enpol.2008.01.014

Johnson, R. B., & Onwuegbuzie, A. J. (2004). Mixed methods research: A research paradigm whose time has come. *Educational Researcher, 33*(7), 14-26.

Keshan, H., Thornburg, J., & Ustun, T. S. (2016). Comparison of lead-Acid and lithium ion batteries for stationary storage in off-grid energy systems. IET Conference Publications, 2016(CP688). https://doi.org/10.1049/cp.2016.1287

Kiani Mavi, R., Goh, M., Kiani Mavi, N., Jie, F., Brown, K., Biermann, S., & A. Khanfar, A. (2020). Cross-Docking: A Systematic Literature Review. *Sustainability, 12*(11), 4789. MDPI AG. Retrieved from http://dx.doi.org/10.3390/su12114789

Lacey, G., Putrus, G., & Salim, A. (2013). The use of second life electric vehicle batteries for grid support. Eurocon 2013, EUROCON, 2013 IEEE, 1255–1261. https://doi.org/10.1109/EUROCON.2013.6625141

Ladier, A.-L., & Alpan, G. (2016). Cross-docking operations: Current research versus industry practice. *Omega, 62*, 145–162. https://doi.org/10.1016/j.omega.2015.09.006

Lo, S.-C., & Chuang, Y.-L. (2023). Vehicle Routing Optimization with Cross-Docking Based on an Artificial Immune System in Logistics Management. *Mathematics, 11*(4). https://doi.org/10.3390/math11040811

Masis, J., Horvath, L., & Böröcz, P. (2022). The Effect of Forklift Type, Pallet Design, Entry Speed, and Top Load on the Horizontal Shock Impacts Exerted during the Interactions between Pallet and Forklift. *Applied Sciences, 12*(14), 7035.

McKinnon, A., Browne M., Piecyk M., & Whiteing A. (2015). 9. *Reducing the Environmental Impact of Warehousing.* In Green Logistics - Improving the Environmental Sustainability of Logistics (3rd Edition). Kogan Page Publishers.

Ministry of the Environment. (2020). Sweden's long-term strategy for reducing greenhouse gas emissions. https://unfccc.int/sites/default/files/resource/LTS1_Sweden.pdf

Preston, N., Maroufmashat, A., Riaz, H., Barbouti, S., Mukherjee, U., Tang, P., Wang, J., Haghi, E., Elkamel, A., & Fowler, M. (2020). How can the integration of renewable energy and power-to-gas benefit industrial facilities? From techno-economic, policy, and environmental assessment. *International Journal of Hydrogen Energy, 45*(51), 26559–26573. https://doi.org/10.1016/j.ijhydene.2020.07.040

Raslavičius, L., Keršys, A., Mockus, S., Keršienė, N., & Starevičius, M. (2014). Liquefied petroleum gas (LPG) as a medium-term option in the transition to sustainable fuels and transport. *Renewable and Sustainable Energy Reviews, 32*, 513–525. https://doi.org/10.1016/j.rser.2014.01.052

Renteria Marquez, A. (2017). Risk Mitigation in the Supply Chain Caused by Multitple Phase-in and Phase-out Components Using SIMIO Simulation [Master thesis, University of Texas at El Paso]. Scholarworks. https://scholarworks.utep.edu/open_etd/535/

Rodrigue, J. (2020). *The geography of transport systems* (Fifth ed.).

Saunders, M., Lewis, P., & Thornhill, A. (2016). *Research methods for business students* (7.th ed.).

Skill Zone Ltd. (2013). *Definition: Workshop*. Association for Qualitative Research (AQR). https://www.aqr.org.uk/glossary/workshop

Stanković, R., Rogić, K., & Šafran, M. (2022). Saving Energy by Optimizing Warehouse Dock Door Allocation. *Energies, 15*(16). https://doi.org/10.3390/en15165862

Suryoputro, M. R., Khairizzahra, Sari, A. D., & Widiatmaka, N. W. (2019). Failure Mode and Effect Analysis (Fuzzy FMEA) Implementation for Forklift Risk Management in Manufacturing Company PT.XYZ. IOP Conference Series: Materials Science and Engineering, 528(1). https://doi.org/10.1088/1757-899X/528/1/012027

Sweden Green Building Council. (2023). Vad är LEED? Sweden Green Building Council. https://www.sgbc.se/certifiering/leed/vad-ar-leed/

Tan, K. S., Ahmed, M. D., & Sundaram, D. (2009). Sustainable warehouse management. In Proceedings of the International Workshop on Enterprises & Organizational Modeling and Simulation (EOMAS '09). Association for Computing Machinery, New York, NY, USA, Article 8, 1–15. https://doi.org/10.1145/1750405.1750415

Torabizadeh, M., Yusof, N. M., Ma'aram, A., & Shaharoun, A. M. (2020). Identifying sustainable warehouse management system indicators and proposing new weighting method. *Journal of Cleaner Production, 248*. https://doi.org/10.1016/j.jclepro.2019.119190

United Nations. (2015). Paris Agreement.

Vis, I. F. A., & Roodbergen, K. J. (2011). Layout and control policies for cross docking operations. *Computers & Industrial Engineering, 61*(4), 911–919. https://doi.org/10.1016/j.cie.2011.06.001

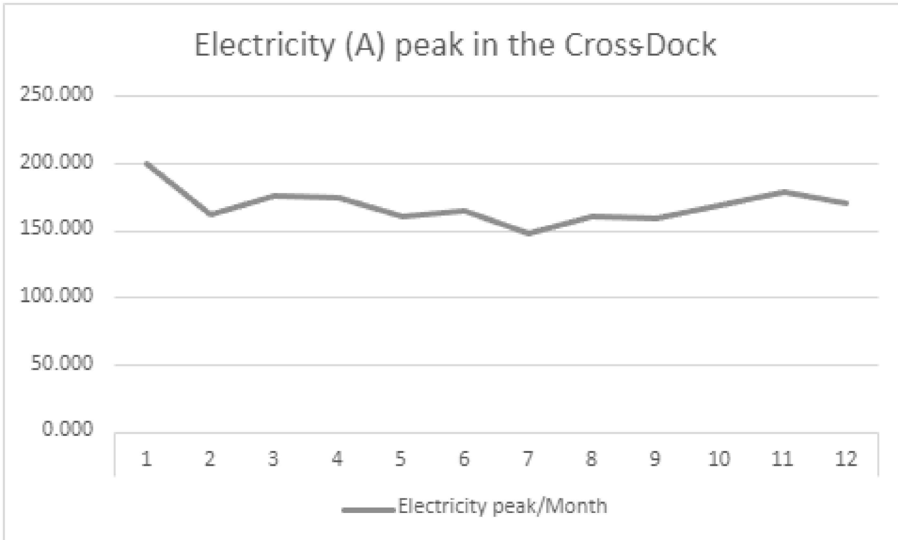
World Economic Forum. (2009). Supply chain decarbonization the role of logistics and transport in reducing supply chain carbon. *Weforum*. https://www3.weforum.org/docs/WEF_LT_SupplyChainDecarbonization_Report_2009.pdf

Xue, Y., Liu, X., Cui, Y., Shen, Y., Wu, T., Wu, B., & Yang, X. (2022). Characterization of air pollutant emissions from construction machinery in Beijing and evaluation of the effectiveness of control measures based on information code registration data. *Chemosphere* (Oxford), 303, 135064.

Yin, R. K. (2014). *Case study research: Design and methods*. Sage publications.

Zeinal Hamedani, A., & Huber, F. (2012). A comparative study of DGNB, LEED and BREEAM certificate systems in urban sustainability. *The Sustainable City VII: Urban Regeneration and Sustainability, 155*, 121-132.

A Appendix Electricity Peaks



DEPARTMENT OF TECHNOLOGY MANAGEMENT AND ECONOMICS
DIVISION OF Supply and Operations Management
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden
www.chalmers.se

CHALMERS
UNIVERSITY OF TECHNOLOGY