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The interplay between cost and quality in wind turbine blade manufacturing plays a critical role in fostering continuous improvement within organizations. While high-quality feedback mechanisms drive better decision-making and performance optimization, they often entail significant resource investments, raising concerns about cost-effectiveness. This thesis explores the dynamic relationship between cost and quality in the wind turbine blades' industry, examining how organizations can balance these factors to achieve sustainable improvements. Through a systematic analysis of theoretical frameworks and collected data, the research identifies strategies for optimizing feedback mechanisms to enhance an aware and accountable workplace environment. By addressing the cost-quality dilemma, this study provides actionable insights for leveraging feedback to drive multidisciplinary continuous improvement with structured methodologies that enhance repeatable and scalable organizational practices.

Das Zusammenspiel von Kosten und Qualität bei der Herstellung von Windturbinenblättern spielt eine entscheidende Rolle bei der Förderung der kontinuierlichen Verbesserung in Unternehmen. Qualitativ hochwertige Feedback-Mechanismen tragen zwar zu einer besseren Entscheidungsfindung und Leistungsoptimierung bei, sind jedoch häufig mit einem erheblichen Ressourcenaufwand verbunden, was Bedenken hinsichtlich der Kosteneffizienz aufkommen lässt. In dieser Arbeit wird das dynamische Verhältnis zwischen Kosten und Qualität in der Windturbinenblattindustrie untersucht, um herauszufinden, wie Unternehmen ein Gleichgewicht zwischen diesen Faktoren herstellen können, um nachhaltige Verbesserungen zu erzielen. Durch eine systematische Analyse der theoretischen Rahmenbedingungen und der gesammelten Daten werden Strategien zur Optimierung von Feedback-Mechanismen aufgezeigt, um ein bewusstes und verantwortungsbewusstes Arbeitsumfeld zu schaffen. Durch die Auseinandersetzung mit dem Kosten-Qualitäts-Dilemma liefert diese Studie umsetzbare Erkenntnisse für die Nutzung von Feedback, um multidisziplinäre kontinuierliche Verbesserungen mit strukturierten Methoden voranzutreiben, die wiederholbare und skalierbare Organisationspraktiken verbessern.

Contents

1.0 Introduction

1.1 Background

The wind power industry has emerged as a cornerstone of the global transition to renewable energy, driven by a short yet consistent history of technical innovation and a growing recognition of the sustainable energy solutions. The roots of wind energy can be traced back thousands of years, however it was not until the 20th century that wind turbines began to evolve into the efficient and capable machines of today (E et al., 2009).

Europe-wise, one of the first large wind turbine was the Tvind, installed not until the mid-1970s (Tvindkraft, 2014). Since then, the wind turbine industry has experienced a significant growth in technology due several wind power development programs with strong governmental support. For example, in the 1980s and 1990s, governments in Denmark, Germany and Spain introduced policies to facilitate the wind power expansion, such as feed-in tariffs for fixed prices for renewable energy. Additionally, agreements and initiatives for clean energy kept boosting the development of powerful and efficient wind turbines.

For reference, in 1987, turbines reached a rated capacity of 250 kW which translates into powering approximately 61 households per year. Nowadays, the newest offshore turbines have a rated capacity of approximately 6.8 MW which would power more than 2 thousand households per year. This means an increase on potential production of more than 3,100 percent in 36 years. Several factors as more efficient engines, longer blades and taller towers have made this production improvements possible.

Nordex SE, founded in 1985, is a leading global manufacturer and provider of wind turbines. With its strong commitment to innovation, sustainability, and efficient energy solutions, Nordex global presence translates into 50 GW output from contracted turbines in over 40 countries, having over 11 thousand wind turbines within its service organization (Nordex SE., 2024).

In the Nordic region, composed by Sweden, Norway, and Finland, Nordex has an installed capacity of 5,000 MW (and 940 MW under construction) which is equivalent to the electricity consumption of 4.7 million households (Nordex SE., 2024). When referring to installed capacity, it means that it is under its service department, which is in charge of the maintenance of the wind parks of a customer portfolio that goes over 20 clients in the Nordic region. For Nordex, the Nordic region is one of the areas in Europe with highest share of renewables in electricity generation, thus the target is to make the Nordic region a steadily growing market with wind power energy production estimated to double by 2030 (Nordex SE., 2024). With such strong commitment and target in the Nordic region, come several opportunities and challenges to maintain an optimal fleet of turbines that meet the contractual availability and production outputs. Therefore, the focus of this research lies on the feedback (communication) process for continuous improvement on blade quality topics.

Specifically, this study focuses on the development of standard and efficient feedback processes to communicate blade quality issues with a strong appeal to historical data, collected results and incurred costs due to identified discrepancies, aiming to support

on the continuous improvement of blade quality and overall blade-related processes in the Nordic region. Understanding the correlation between communication processes and continuous improvement is necessary to provide a high-quality service, to maintain optimal installed turbines, and to incorporate newer fleets smoothly. Key procedures in this study include data analysis, cost understanding and forecast, and process identification and development to ultimately produce a repeatable and scalable communication process based on backed-up feedback. Moreover, this proposal intends to be the base of further developments as the market expands and requirements change.

Employing Total Quality Management (TQM) and feedback-driven changes, this study proposes a systematic approach to assess the current state of the communication process to provide feedback to the corresponding departments and contribute to Nordex's premium service and innovative development of products.

1.2 Problem Statement

Nordex's ambition to keep a steady growth in the Nordic region offers an opportunity to study the processes of the Service department for communicating blade quality deviations in relatively new products, improve and refine them according to their current and future needs. Although the existing processes have been successfully utilized, establishing a strongly focused process with operational and economical data is vital to keep up with existing and new fleet of turbines and blades sets in the coming years.

With the transition to a leading multi-GW provider in the Nordic Region, it is essential to verify and adjust current communication processes to ensure consistent feedback for quality control in blades, as they represent a high portion of maintenance works due to the challenging environmental conditions of the Nordics. Nordex already has an established process to communicate defects and create claims on them, and the focus now is on adopting these existing processes with stronger argumentation to enhance continuous improvement of the services provided by Nordex Nordic Service department. Considering the Service department as maintenance provider, their product rely on offering the highest degree of service for optimal functionality, while also been responsible of communicating recurrent and extraordinary blade quality deviations for a better service in the future. More than a problem, this transition is an opportunity to re-verify and strengthen processes by applying strict methodologies of data analysis to understand the connection between feedback and continuous improvement in blade quality and maintenance.

1.3 Project Objectives

This study aims to use the current opportunity by the constant growth, innovation and development of Nordex to evaluate procedures and gain a better understanding of the contributing factors that may hinge their service agreements if not addressed promptly. By employing TQM and feedback-driven changes theories, the research will enhance the comprehension and correlation of communication processes that could improve blade quality in the manufacturing, installation and service stages based on economical and

operational data collected throughout the year 2024 by the Nordex Nordic Blade Service team. This research will contribute to Nordex's commitment to efficient, innovative and high quality products by supporting their continuous improvement with additional inputs. The main objectives of this study can be represented by the following bullet points:

1. Understanding the economical and operational impact of blade quality deviations for Nordex's Service department in the Nordic region in 2024 for blades installed in 2023.

2. Suggesting methodologies to identify and evaluate blade quality deviations promptly during manufacturing, installation and early service stage.

3. Creating a feedback-driven communication process for Nordex's Service department with a strong appeal to continuous improvement for blades and maintenance.

4. Proposing tools to display economical implications as a support for decision-making in a long-term perspective, aligning with Nordex's goals.

1.4 Scope and Limits

Although the study addresses various considerations, its scope is specifically limited to examining the current situation of the understanding and communication process for blade quality deviations across the fleet installed in 2023 in the Nordic region, and incorporating feedback-driven processes to align Nordex's premium service goals with its execution to maintain their innovation and development at the highest level. Identifying the contributing factors to a strong continuous improvement plan is crucial for the effective execution of each of the steps in the communication processes among Nordex's departments, enhancing the delivery of quality products.

The main concepts involved in this study revolve around economical and operational metrics, quality assurance methodologies, feedback-driven communication processes, and long-term vision for continuous improvement. This thesis is organized into several steps, each addressing specific research objectives. The introduction focuses on outlining the background and its relevance, main objectives, scope and structure of the study. The second stage includes a literature review that comprehensively examines relevant literature on Total Quality Management (TQM), continuous improvement, feedback-driven changes, high quality manufacturing, and costs forecasts. Subsequent stages delve into the methodology employed, the results obtained, and discussions on the findings, culminating in conclusions and recommendations for future research, aligned to the established project objectives.

2.0 Literature review

2.1 Total Quality Management

Total Quality Management (TQM) it is a complete management philosophy focused on the continuous improvement of all processes and divisions within an organization to improve customer satisfaction. The characteristics of TQM typically include the following principles that require better participation from all employees in a company to improve processes, products, services, and culture (Barrie G. Dale, 2003).

As TQM has developed through years, it has been establishing the principles in Figure 1, which are key in order to succeed in a TQM implementation.

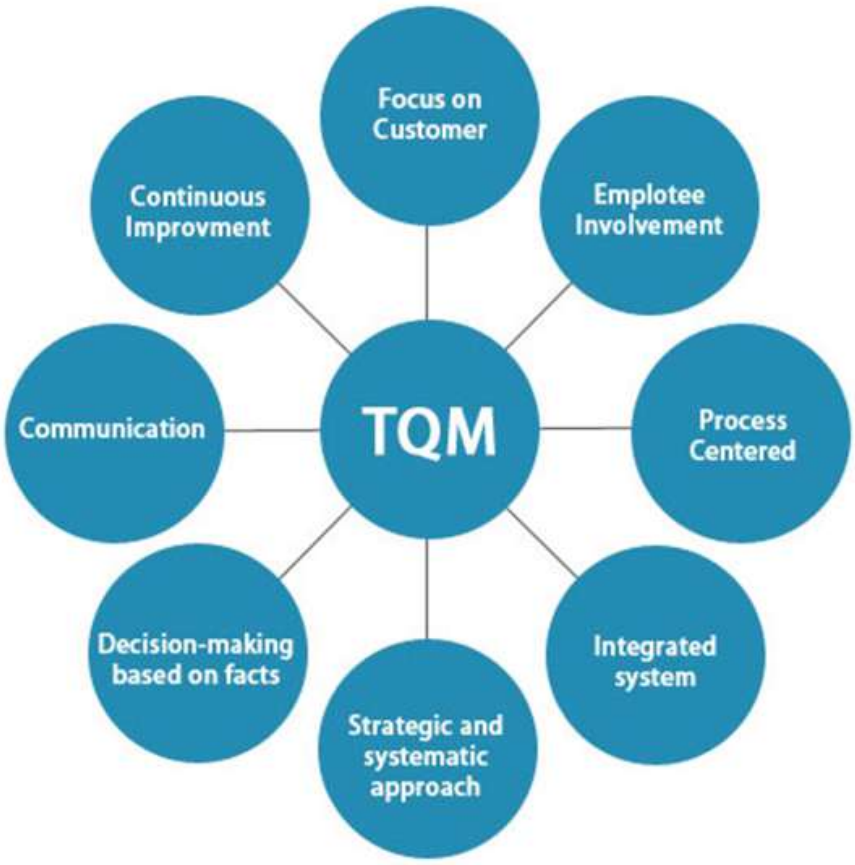

Figure 1: Total Quality Management (Educba, 2019)

Customer Focus

Central to TQM is that management systems and processes should deliver what the customer needs. Thus, every decision taken under Total Quality Management aims at improving customer satisfaction by supplying products and services that meet the demands and expectations of customers. TQM says the customer defines quality. Therefore, organizations should always try to meet the expectations of their customers or even exceed

those expectations. It creates elaborate feedback loops by fostering a customer-centric model, which grants the ability to adjust processes, products, and services subtly at all times. Bhujabal and Swain (2020) suggest that by developing a robust customer-centric focus as a part of TQM, businesses can observe elevated levels of satisfaction resulting in high extents of customer loyalty and thereby higher retention (Khyat et al., 2020).

Total Employee Involvement

A second basic tenet of TQM is the participation by all employees in the pursuit of quality upgrades. This culture created by TQM ensures that every single employee, from top management to entry-level workers, is involved in enhancing the quality of products and services offered by an organization. Staff are empowered and encouraged to take responsibility for the quality of their work and make suggestions. A study by Dale, Van der Wiele, and Van Iwaarden (1999) highlights that enterprises with complete employee involvement tend to provide more innovative solutions and improved problem-solving capabilities. Since TQM involves employees in decision-making roles, it encourages teamwork and accountability on both individual and organizational levels, helping to achieve better goals (Barrie G. Dale, 2003; Talib, 2013).

Continuous Improvement

Kaizen, also called continuous improvement, is one of the basic principles of TQM. It reflects the idea that organizations should continually enhance their processes, products, and services. This principle pushes the notion of eliminating waste and inefficiencies by building a culture focused on incremental improvements. Small steps forward in performance and quality can yield significant long-term improvements. Talha (2004) explains that organizations practicing TQM adopt a philosophy of never-ending improvement, where the focus is not only on achieving goals but continuously aiming at higher standards. This helps organizations remain competitive and adaptive in a dynamic landscape (Talib, 2013).

Importance of TQM

Any organization dedicated to sustaining success and winning its way in the market would attach great importance to TQM. TQM is an organization-wide program that integrates the quality development, maintenance, and improvement efforts of everyone in the firm—from top management to en-try-level workers. TQM creates a culture of both accountability and innovation by involving all employees to seek continuous improvement. The implementation of this method ensures that organizations will meet and even surpass customer expectations, resulting in higher customer satisfaction and loyalty. The application of TQM, as indicated by Talib (2013), leads to noteworthy operational efficiency, production quality, and organizational execution. Additionally, with a stronger focus on data-driven decision-making and process optimization, organizations can reduce waste and costs while being more effective in resource utilization. The TQM philosophy helps organizations meet the challenges of a globalized and hypercompetitive

business world by providing them with the concepts and methods to succeed (Talib, 2013; Tambare et al., 2022).

2.2 Continuous Improvement

Continuous improvement is a core principle throughout quality management processes such total quality management and Enterprise Resource Planning (ERP), designed to create long-term excellence through continuing incremental changes. The importance to establish continuous improvement procedures can vary within companies. However, continuous improvement has been established, throughout many authors, as Plan, Do, Check and Act, as can be seen in Figure 2. Still, this can vary significantly according to the need of an organization. The capacity of it to establish adaptable, flexible processes that enable organizations to stay competitive and responsive to market needs is what makes it relevant today. The significance of continuous improvement, its applicability to organizational success, and its innate connection to customer satisfaction are covered in this section (Jha and Joshi, n.d.).

Figure 2: Plan, Do, Check and Act (Arena Solutions, 2023)

Relevance of Continuous Improvement

Continuous improvement plays a fundamental role in contributing organizations to maintain high operational efficiency, minimize waste, and improve the quality of their products and services. Instead of relying on one-off changes, it promotes a culture where all employees are actively involved in finding ways to enhance performance and product delivery. Jha and Joshi (2007) emphasize that within frameworks like Total Quality Management, continuous improvement enables organizations to consistently meet customer expectations by providing high-quality products and services in a timely and

efficient manner. This collaborative approach ensures that improvements occur at every level of the organization (Jha and Joshi, n.d.).

Several studies in both industrial and service sectors, methodologies such as Kaizen, Lean, and Six Sigma often drive as main continuous improvement efforts. As Diamandescu (2016) notes, these strategies help organizations systematically eliminate errors and inefficiencies, enabling them to perform at their best. This not only boosts operational effectiveness but also enhances profitability and strengthens competitiveness in the marketplace (Diamandescu, n.d.).

Moreover, a continuous improvement policy allows companies to standardize quality within the organization. Studies like Iyer have solid foundations on how to establish a continuous improvement system (CIS), since it enables organizations to increase performance in a steady and scaled incremental growth. In addition, Iyer was able to demonstrate with this study that a continuous improvement strategy can be applied to any type of business. Iyer was able to successfully apply a CIS in the education sector and perform customer feed-back driven improvements. However, studies also state that the implementation of continuous improvement policies are unchallenging, the challenge that face a company is to maintain those new implementations through time; an unsuccessful implementation leads to time waste and costs (Gurumurthy Iyer, n.d.).

Relationship between Continuous Improvement and Customer Satisfaction

Continuous improvement is not only referred to refining internal operations; it is also fundamental for maintaining customer satisfaction. A core aim of this strategy is to understand and meet customers ever-changing needs. According to Iyer (2019), organizations that adopt continuous improvement systems creates a link with customer expectations by creating a culture that is responsive to feedback. This proactive approach allows companies to quickly address customer complaints, adjust, and enhance the overall customer experience.

Customer feedback plays a central role in driving continuous improvement. When companies actively gather and analyze feedback, they can make targeted changes to their products and services that directly respond to customer concerns. Tools like Net Promoter Score (NPS) surveys are commonly used to track customer satisfaction and gather actionable insights. By leveraging NPS data, companies can monitor satisfaction trends and fine-tune their strategies as needed (Saludin and Tan, 2010). This data-driven approach has been shown to significantly boost customer loyalty and overall satisfaction. The following figure illustrate this importance:

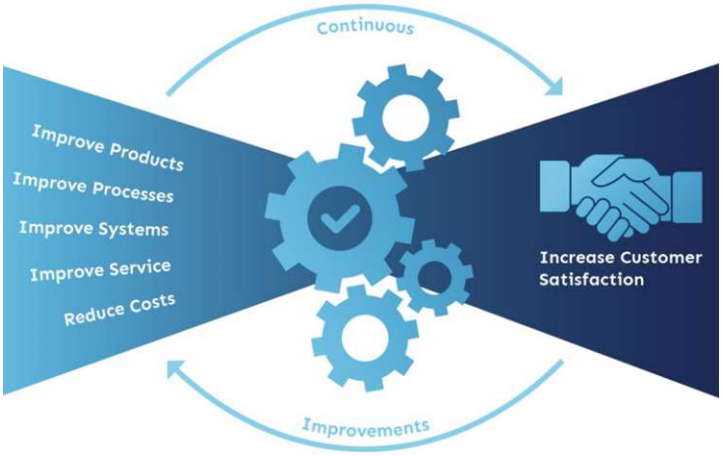

Figure 3: Customer Satisfaction and Continuous Improvement (OPTIMOD, 2023)

For instance, service-based businesses integrate customer satisfaction surveys to ensure a steady stream of feedback. Companies such as Amazon and Toyota use these surveys to refine products, personalize services, and quickly address issues. Many of these feedback systems are automated, allowing for real-time improvements. Antić and Bogetić (2024) emphasize that by responding promptly to customer feedback through continuous improvement methods, companies can resolve problems faster and consistently meet customer expectations (Antić and Bogetić, 2024).

This connection between continuous improvement and customer satisfaction is even stronger in organizations that use closed-loop feedback systems. In these systems, customer insights are not only collected but also acted upon methodically. This ensures that feedback directly informs changes to products or processes, ultimately improving customer satisfaction. As Diamandescu (2016) illustrates, continuous improvement strategies like Kaizen not only reduce defects but also help companies maintain a competitive edge by ensuring high product quality. When customers consistently receive reliable, top-notch products and services, their trust grows, leading to lasting loyalty.

A study by David (2018) on quality management in Kenyan middle-level colleges showed that institutions that actively sought and acted on student feedback saw a significant boost in satisfaction. This feedback-driven continuous improvement resulted in better course offerings, improved services, and stronger overall performance. The study concluded that actively engaging with customer feedback through structured continuous improvement is key to increasing satisfaction across various industries (David, 2018).

Similarly, Toyota's "Customer First" approach gathers input on vehicle performance and user experiences, leading to improvements in safety features, comfort, and reliability. By continuously refining its processes based on customer insights, Toyota has maintained its reputation as one of the most reliable automakers in the world.

To conclude, numerous studies highlight how feedback-driven improvements significantly enhance satisfaction rates across various sectors. This approach is not only crucial within industries but also deeply embedded in everyday life. Whether in business operations, education, healthcare, or personal interactions, feedback plays a vital role in

shaping decisions and fostering continuous improvements. The feedback loop allows for constant adaptation, ensuring that services, products, or interactions evolve to meet expectations more effectively. Changes are, in most cases, the direct result of thoughtful responses to feedback, which serves as a natural mechanism for enhancing processes, regardless of the industry or context. This iterative process of receiving, analyzing, and acting on feedback ensures that organizations and individuals alike remain responsive and relevant in an ever-changing environment, ultimately driving higher levels of satisfaction and success.

2.3 Feedback-driven Changes

Feedback-driven changes are essential for implementing continuous improvements within a competitive industry framework. By incorporating insights from various stakeholders—such as customers, employees, and process data—organizations can swiftly respond to evolving needs and inefficiencies. This approach enhances not only product quality but also operational efficiency and overall performance. In the following section, we will delve into the different types of feedback that drive these changes and explore their impact on efficiency. In addition, if feedback is properly managed, well-structured changes can be applied in order to achieve a 360 operational efficiency in an organization (Bracken and Rose, 2011). To elaborate better, different feedback will be approached. The following diagram exemplifies of what a continuous feedback loop consists in companies.

Figure 4: Feedback Loop (Qaizen - Listen, 2022)

Customer Feedback

One of the most significant types of feedback in a total quality management system is customer feedback, which provides clear insights into how effectively goods and ser-

vices meet consumer expectations. Online reviews, complaints, and surveys are some of the tools that offer useful information about the general customer experience. Gremyr, Birch-Jensen, and Kumar (2022) point out that digital feedback procedures assist companies in promptly recognizing and resolving quality-related concerns, allowing them to co-create value by guaranteeing that enhancements satisfy client expectations. In addition to being essential for improving products, customer input is also critical for streamlining the processes involved in providing services (Gremyr et al., 2022).

Employee Feedback

When determining inefficiencies and areas for improvement in operational procedures, employee feedback becomes essential. People working in manufacturing or customer service frequently offer a unique viewpoint on problems or bottlenecks that higher management might miss. Systems that take employee and other user comments into account are essential for preserving good process quality, as noted by Nick (2006). This internal input helps develop operational methods and sustain high-quality standards over time (Nick, 2006).

Data Feedback

Feedback-driven data placing, and analysis are crucial for refining organizational operations. Hahmann (2014) describes how data clustering techniques, which are also applicable to organizational quality management, can be driven by feedback systems. Organizations can make data-driven decisions that greatly improve product quality and expedite operational procedures by examining trends and reacting to input (Wolfgang Lehner and nat Thomas Seidl RWTH Aachen, n.d.).

Efficiency of Feedback

Feedback-driven adjustments prove successful because they give businesses access to practical, actionable data which allows them focus on the areas that really need improvement. Efficiency comes from concentrating efforts on the most important input rather than making general, ill-considered changes.

- Focused changes: Organizations can develop focused changes by utilizing input from workers, customers, and procedures. Gremyr et al. (2022) highlight that digitalized consumer interactions provide feedback that may be used to pinpoint areas where procedures fall short of expectations and make the necessary modifications and adjustments.
- Proactive Problem Solving: By using feedback systems, businesses can spot any problems early on and take action before they get out of hand. Nick (2006) provides an example of how feedback-driven systems might support the upkeep of high standards by facilitating preemptive modifications to avert issues in the future.

2.4 High Quality Manufacturing

High-quality manufacturing is all about creating products that consistently live up to, or even surpass, customer expectations in terms of performance, reliability, and durability. This process focuses on precision, efficiency, and meticulous attention to every detail during production. By ensuring that products are free from defects and meet rigorous quality standards, manufacturers maintain a high level of excellence. Achieving this level of quality involves tight process control, continuous monitoring, and strict adherence to industry standards and certifications. As Kiran (2017) points out, high-quality manufacturing relies on advanced technologies, a skilled workforce, and optimized processes to enhance efficiency while minimizing waste and errors. This not only results in superior product quality but also boosts overall operational performance, helping businesses stay competitive in the market (D.R. Kiran, 2017).

Quality Controls and Tools

In manufacturing, quality control typically involves a range of systematic procedures aimed at ensuring that products consistently meet the required standards throughout production. These controls include inspections, testing, and the use of statistical quality control (SQC) methods, such as sampling and process monitoring. Common techniques like Six Sigma, which focuses on reducing defects and variability, and Statistical Process Control (SPC), which uses data to monitor and manage production processes, play a crucial role. Many organizations also implement quality audits and certification programs, such as ISO 9001, to maintain consistent adherence to these standards. By applying these controls, manufacturers can identify and address potential issues before products reach the market, ensuring both reliability and compliance with specifications (Easton and Jarrell, 1998) .

Techniques for a Better Quality

Manufacturing employs several techniques to enhance product quality. Lean manufacturing aims to eliminate waste and streamline processes, improving both efficiency and quality. Another widely used method is Six Sigma, which focuses on reducing defects by leveraging data-driven strategies and statistical tools to control process variability. Total Quality Management (TQM) takes a holistic approach, engaging every employee in the pursuit of quality improvements. Tools like Failure Mode and Effects Analysis (FMEA) help identify potential problems in products and processes early, allowing for proactive corrections. Continuous improvement frameworks such as Kaizen promote small, incremental changes that, over time, result in significant quality enhancements. When applied effectively, these techniques can greatly improve both product and process quality, ultimately boosting customer satisfaction and reducing costs (DataPine, n.d.; Dhafr et al., 2006).

In addition to Lean Manufacturing, Six Sigma, and Total Quality Management (TQM), other advanced techniques can further improve both product and process quality. Just-In-Time (JIT) manufacturing focuses on reducing waste by receiving materials only when

they are needed in the production process, which cuts down on inventory costs and enhances efficiency. Root Cause Analysis (RCA) is another key technique used to uncover the underlying reasons for defects or issues in manufacturing processes. By addressing the root causes, companies can implement effective solutions that prevent the problem from recurring. Design of Experiments (DOE) is a valuable tool that optimizes processes by testing various variables to identify the ideal conditions for production. Additionally, Quality Function Deployment (QFD) ensures that customer needs are translated into specific technical features during product development, aligning the final product with customer expectations. Together, these techniques create a comprehensive framework that enhances the quality and reliability of manufacturing processes, ultimately leading to greater customer satisfaction and lower production costs (D.R. Kiran, 2017; Statistical Manufacturing Journal, 2002; Tambare et al., 2022).

2.5 Costs Forecasts

Forecasting costs is a critical part of financial planning and management, allowing organizations to anticipate future expenses and make strategic decisions. Cost forecasting can be broken down into several categories based on the focus area, such as operating costs, project costs, production costs, and broader financial forecasting. Each of these categories demands distinct approaches and tools designed to address its specific needs. More-over, operating cost forecasts might rely on historical data to project day-to-day expenses, while project cost forecasts often require detailed budgeting and risk assessment methods to estimate the financial requirements of specific initiatives. Similarly, production cost forecasting may involve models that factor in variable and fixed costs to predict the costs of manufacturing products. Broad financial forecasting generally encompasses a wider range of factors, integrating multiple areas like market conditions, operational efficiency, and industry trends to create a comprehensive financial outlook (McMullan, 1996) . By tailoring forecasting methods to each category, organizations can improve the accuracy of their predictions, enabling better budgeting, resource allocation, and long-term financial planning. The Figure below lists the costs that are relevant to forecast, and which will be explained repectively.

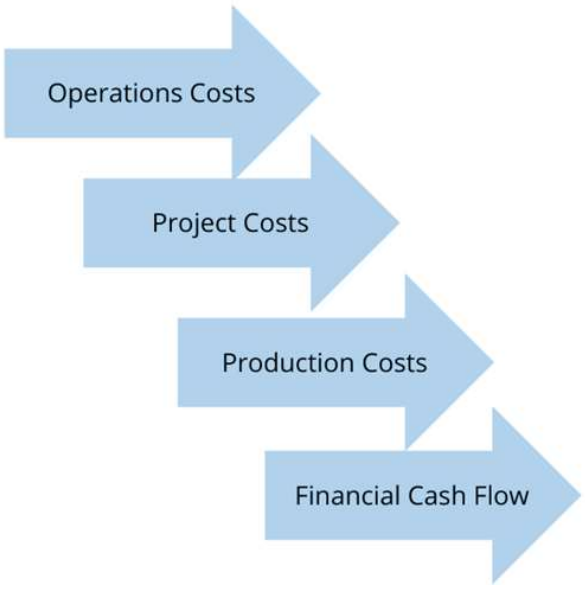

Figure 5: Forecasting costs (McMullan, 1996)

Operating Costs Forecasting

Operating costs are the routine expenses necessary to maintain the daily operations of a business. These typically include items like wages, utilities, rent, and office supplies. Accurately forecasting these costs is essential for businesses to anticipate how their regular expenses will change over time. L.E. McMullan (1996) highlighted the significance of using project management systems to predict operating costs, ensuring both efficiency and long-term sustainability. To create a reliable forecast, businesses often rely on historical data analysis to understand past spending patterns. Additionally, trend projections are used to estimate future changes in costs, while differentiating between fixed costs (such as rent) and variable costs (such as utilities) is key to understanding which expenses may fluctuate. By considering these factors, companies can build more accurate forecasts that help with budgeting and maintaining operational stability.

Project Costs Forecasting

Project cost forecasting involves estimating the resources and expenses needed to successfully complete a project. This typically includes costs for labor, materials, equipment, and overheads. To accurately forecast project costs, organizations often use methods like bottom-up estimation, which breaks down the project into smaller tasks and estimates costs for each, or top-down estimation, where the total project cost is estimated based on similar past projects (Al-Zwainy and Hadal, 2016). FMS Al-Zwainy and NT Hadal (2016) explored the role of artificial intelligence in improving project cost forecasting, especially in fields like construction. They highlighted how machine learning and AI technologies can enhance the accuracy of cost estimates by analyzing vast datasets and predicting patterns that might be difficult for human estimators to detect. Additionally,

incorporating contingency plans is crucial for managing unexpected costs, helping to ensure that project budgets remain realistic and adaptable. By including provisions for unforeseen expenses, organizations can make their project cost forecasts more robust and reliable, reducing the risk of budget overrun.

Production Costs Forecasting

Production costs refer to the expenses involved in manufacturing products, which typically include raw materials, direct labor, and overhead. Accurately forecasting these costs is vital for businesses to maintain profitability, as it helps manage and anticipate fluctuations in expenses. Smith and Offodile examined how forecasting techniques in supply chain management can assist businesses in assessing the impact of changes in raw material prices and production overhead on overall costs. To optimize production and keep costs under control, companies can use tools such as cost-volume-profit analysis, which helps assess how changes in production levels affect costs and profits. Additionally, statistical forecasting methods provide valuable insights into trends and potential fluctuations, enabling businesses to make more informed decisions about production scheduling and resource allocation. These approaches collectively help organizations maintain efficient production processes while effectively managing their costs (Smith and Offodile, 2007).

Financial Forecasting

Financial forecasting integrates various areas of cost forecasting—such as operating costs, project costs, and production costs—to predict an organization's future financial health. By accurately forecasting, businesses can better anticipate profit margins, manage cash flow, and plan for capital expenditures. Shahriar et al. (2021) explored multiple financial forecasting methods, including the application of advanced machine learning algorithms like random forests, to improve the accuracy of predicting project evaluation costs and overall financial outcomes. By adopting these techniques, companies can better anticipate financial risks and make more in-formed decisions, ultimately improving their financial stability and performance (Shahriar et al., 2021).

Forecasting Costs Techniques

- Historical Data Analysis: Businesses collect and examine past cost data to identify trends, seasonal fluctuations, and consistent patterns. This data is then used to predict future expenses. For example, if a company has seen labor costs rise by 3 percent annually for the past five years, it can forecast a similar increase for the upcoming year. Financial tools like spreadsheets or specialized software are commonly used to model this data and generate forecasts.

- Scenario Planning: Organizations develop multiple scenarios based on possible changes in external factors, such as market shifts or supply chain disruptions. For each scenario—optimistic, pessimistic, or most likely—cost estimates are adjusted

accordingly. For example, a manufacturer might prepare scenarios where raw material prices increase by 10 percent, decrease by 5 percent, or remain stable. These scenarios provide a range of potential outcomes, helping the business plan for different possibilities.

- Bottom-Up Estimation: Each component of a project is broken down into smaller tasks, and individual cost estimates are calculated for each. For instance, in a construction project, estimates for labor, materials, and specific tasks (like plumbing or electrical work) are calculated separately. Once the costs of these individual components are determined, they are combined to form a total project cost estimate. This approach requires detailed information for each component and is typically used for complex projects.
- Top-Down Estimation: A total project cost estimation is established based on high-level data, past experience, or industry benchmarks. This overall estimate is then divided into portions for individual components or tasks. For example, a software development project may have a total cost estimated at 500,000 euros, which is then allocated to design, development, testing, and other phases. This method allows for quicker estimates but may require refinement as the project details become clearer.
- Cost Volume Profit (CVP) Analysis: Businesses analyze the relationship between fixed and variable costs, production or sales volume, and profitability. Using CVP analysis, companies can identify the break-even point—the level of sales where total revenues cover total costs. This helps organizations understand how changes in production levels or sales volumes impact overall costs and profits, allowing them to adjust strategies for pricing, production, or sales targets accordingly.

Return of Investment

Return on Investment (ROI) is a crucial financial metric that helps assess the profitability or efficiency of an investment. It evaluates the return generated compared to the cost of the investment, providing insight into how well the investment is performing. ROI is usually expressed as a percentage, making it easy to compare the profitability of different investments (Brealey et al., 2011).

The formula for calculating ROI is:

$$\text{ROI} = \left(\frac{\text{Net Profit (Return)} - \text{Investment Cost}}{\text{Investment Cost}} \right) \times 100$$

Where:

- Net Profit (Return) refers to the total earnings or gain from the investment.
- Investment Cost is the initial amount spent on the investment.

To understand ROI properly is important to exemplify on how financial authors apply the formula. For example, if a company invests 100,000 euros in a project and earns 150,000 euros in returns after five years, the ROI would be:

$$ROI = \frac{150,000 - 100,000}{100,000} \times 100 = 50\%$$

Knowing about ROI and its importance is crucial for the decision-making on whether to bring certain improvements of a significant amount of money or not. In a nutshell, all of the topics presented are related to the project, as several of their methodologies will be implemented and taken into account for the resolution of the objectives.

3.0 Research Material and Methods

This section presents a comprehensive analysis of Nordex's current situation based on collected and analyzed information. It begins with the data collection structure, which includes literature reviews of past studies, secondary data collection, regular and informal stakeholder meetings/feedback, as well as on-site observations and day-to-day data capture. Following this, it details blade-related terminology, the current status of blade data utilization, blade manufacturing process, and post-installation blade quality checks. Additionally, it takes into account the communication processes utilized for blade-related topics in the Nordic region. This analysis provides an integral view of the current state of Nordex in the aspects previously mentioned, exploring their strengths, weaknesses and limitations, to then dig into the development of possible implementation strategies of the objectives set for study, alongside their corresponding impact on the company's practices.

3.1 Data Collection Methods

The data collection process was systematically organized, considering all relevant methodologies and practices in use by organization. The following points debrief each of the methods, pinpointing their purpose and relevance.

- **Literature review of past studies:** The past comprehensive reviews of research were done for setting up the state of the art, knowledge base and background. This included studies on Total Quality Management, kaizen, continuous feedback loop, techniques for better quality, and costs forecasts.
- **Secondary data collection:** The recompilation of data from the system is necessary to create a scope of work to plan and execute throughout the repair season. The aim is to not only extract it for a sole purpose, but to process and create significant output for an efficient identification of defects and a detailed communication to the relevant stakeholders.
- **Stakeholder regular meetings:** These weekly/bi-weekly meetings are arranged every year for around 8 months with blade-related topics stakeholders. The aim is to provide updates on blade topics in the Nordics, them varying from cost updates, inspection findings, extraordinary cases, repair plans, among other recurrent feedback.
- **Informal stakeholder feedback:** These informal feedback happens throughout the whole year with the different blade-related topics stakeholders. The aim is to collect constant ideas of improvement based on the current state of functionality of the topic addressed.
- **In-situ observation:** This observation process happened at the blade factory premises for a deeper understanding on the manufacturing process. Such observations facilitated a clear view on the processes followed to produce blades, highlighting their standardization methods for quality blades.

- **Day-to-day data capture:** The daily experience acquired during work is highly-relevant for assessing the viability and practicality of the existing and proposed processes.

3.2 Wind Turbine Blade Components and Terminology

Before deep diving into blade-related processes, it is key to identify and visualize the main components of a blade, as well as understanding the terminology used. The figure below displays the key components of a blade:

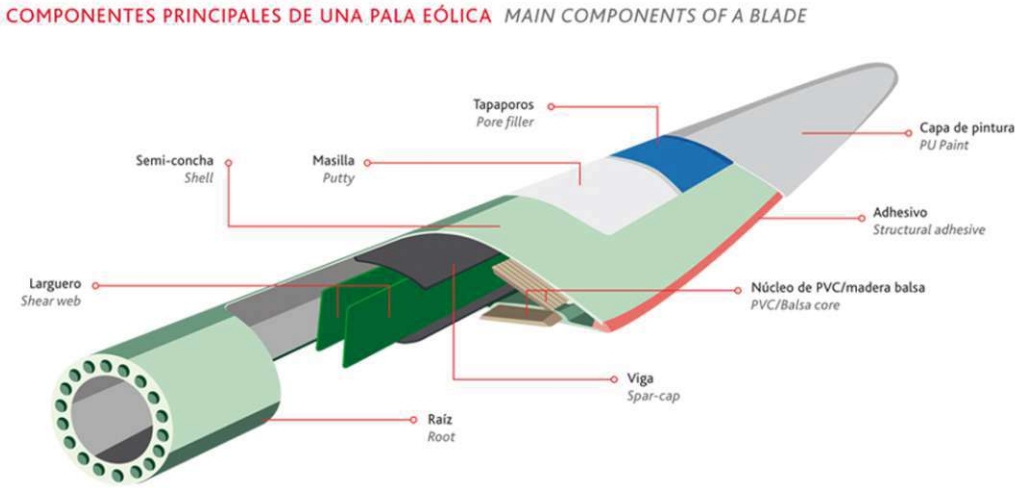

Figure 6: Main Components of a Blade (Acciona, 2024)

The components displayed on the figure above represent the main structural parts of a blade, which are assembled throughout the manufacturing process. The scope of the project focuses on a deeper analysis of the quality deviations, which requires an understanding of the terminology used for the deviation record and documentation. After an insightful conversation with one of the company's blade experts, the most important terms were debriefed and listed below.

- Leading Edge (LE): the foremost edge that first makes contact with the medium the blade is designed to interact with, which in this case is air/wind. In other words, it is the edge that leads as the blade moves across the air.
- Trailing Edge (TE): the rear edge that follows after the leading edge as the blade moves through its medium, air. Basically it is the edge where the flow of air detaches and exits the blade.

Figure 7: Illustration of the Leading and Trailing Edges (Nordex, 2021)

- Distance from flange (DF): the measurement from the blade root flange to a specified point along the length of the blade. The blade root flange is the circular interface at the base of the blade where it attaches to the hub. This is used as a reference for defining locations across the blade for analysis, manufacturing, installation, etc. Also, it is measured along the blade's longitudinal axis, as shown in the figure below.

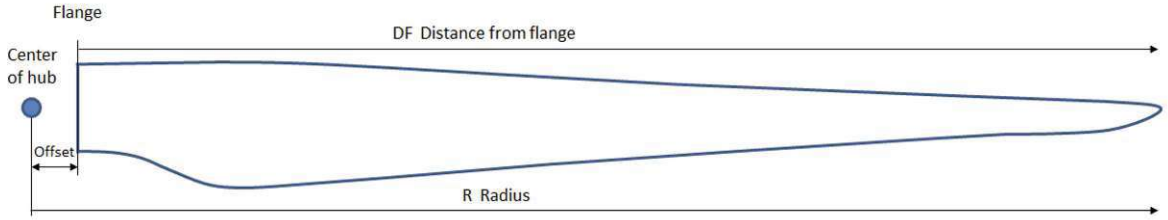

Figure 8: Illustration of the Distance from Flange (DF) (Nordex, 2021)

- Profile depth (PD): the chord wise thickness of the blade's profile at a specific location along its length. The profile depth typically varies along the length of the blade, with higher depths near the root and lower depths near the tip. However, when it comes to defining a location, the PD is often expressed as a percentage because of the uneven dimensions across the blade's length. Also, it is typically measured along the blade's transversal axis.
- Suction side (SS): the curved surface of the blade that faces away from the wind direction when the turbine is operating. The suction side experiences lower pressure due to its curvature, compared to the pressure side.
- Pressure side (PS): the flatter (or less curved) surface of the blade that faces towards the wind direction when the turbine is operating.

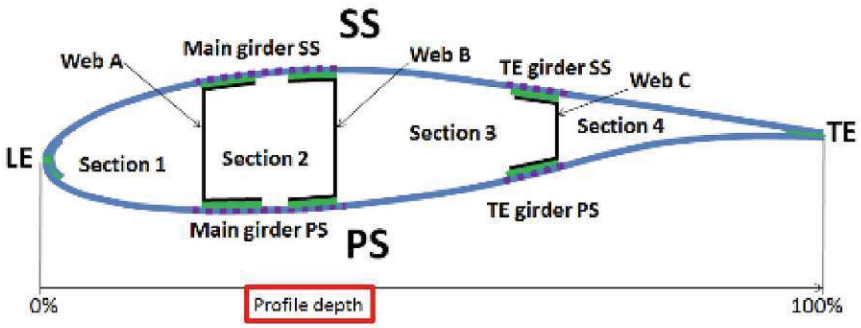

Figure 9: Illustration of SS, PS and Profile Depth (PD) (Nordex, 2021)

Knowing the terminology listed above permits a comprehensive grasp of the content and processes presented in this project. In the following sections, the terms described will be repeatedly mention as they are strictly related and typically used for deviations' record and documentation. Additionally, they will be pinpointed numerous times in tables and graphs for data visualization.

3.3 Current Status of Blade Data Utilization

Nordex Nordic Blade team is part of the Regional Field Support department from Nordex Service in the Nordic region, which is in charge of blade repairs and maintenance, their planning and execution. Throughout 2024, there were more than 13,100 data entries uploaded to the system from the older and newest blades. These data entries correspond to findings from all types of inspections, meaning drone inspections, thermal inspections, lightning protection system (LPS) inspections, internal and external inspections, etc. performed by specialized subcontractors.

Currently, this data is extracted by the Blade team from the system in order to identify which findings require actions, based on the categorization established by the company's guidelines. The extracted data consists on the following categories:

- Ticket Number
- Finding ID Number
- Windpark
- Turbine Number
- Blade Number
- Finding Category
- Quality Deviation Type
- Subcomponent Affected
- Deviation Size
- DF - Start
- DF - End
- PD - Start
- PD - End
- Repair Instructions
- Total Repair Time
- Root Cause
- Comments (from technical department)

These categories were specifically chosen as they are most useful for the planner to understand findings, identify their repair time-frame, and assign them to the corresponding repair team. The data from the older fleet of turbines, with known issues and expected maintenance, is utilized merely for planning purposes. On the other hand, the data from the newest fleet of turbines is processed once by the support coordinator to identify root causes, escalate major findings, and provide cost estimations for their respective repairs. Additionally, this data can be transferred to the claim management team in order to evaluate the possibility on placing claims against manufacturing or installation departments to cover the costs of those findings, if applicable.

As mentioned, the data is partly utilized to understand the cost implications of the findings. The methods utilized to make the cost estimations are worth highlighting, as they follow a traditional yet effective approach for realistic amount considering all possible variables. First of all, since these findings' repairs are done by third-party specialized subcontractors, the support coordinator estimates what is their total hourly rate - meaning the price per working hour including all additional costs - by filling in the following data:

		CONTRACTUAL RATES								VARIABLES								COSTS DISTRIBUTION							TOTAL	WHR
Subcontractor		Working Rate (€/H)	Downtime Rate (€/H)	Materials (%)	Distance HQ-WF (km)	Travel by car - techs. (€)	Travel by car - 3 techs. + platform (€)	Additional Travel Expenses (€)	Accomodation & Allowance (€)	Starting Date (CW)	Ending Date (CW)	Hours On Site (h)	Weather Downtime (%)	Working Hours (h)	Downtime Hours (h)	No. Technicians (-)	WF-WF Distance (km)	Rotation Cycle (weeks)	Working Cost (€)	Downtime Cost (€)	Material Cost (€)	HQ-WF Cost (€)	WF-WF Cost (€)	Additional Travel Cost (€)	Acc. & Ad. Cost (€)	Total Cost (€)	Work Hourly Cost (€)
Name																											€ 275,415.00	€ 242.87
Team	Task	€ 100.00	€ 75.00	10%	1000	€ 1.50	€ 1.80	€ 2,000.00	€ 150.00	13	40	1620	30%	1134	486	3	500	4	€ 113,400.00	€ 36,450.00	€ 11,340.00	€ 1,500.00	€ 10,125.00	€ 27,000.00	€ 75,600.00	€ 275,415.00	€ 242.87
	Task																											
	Task																											

Figure 10: Representative Total Hourly Rate Calculator

This calculator takes into account all the contractual rates, variables in time and resources, to ultimately add up the costs for each category and dividing per number of working hours. This approach is relevant as it follows a model that can be replicated in any area with a similar cost structure. Back to the use of blade data utilization, the so-called total hourly rate is utilized to estimate the cost of a repair, by multiplying it by the "Total Repair Time" from the data extract. With this, it is possible to assess the first-hand cost impact that the repairs have, to then be accurately communicated to the relevant stakeholders.

Wrapping up, the three points below summarize the current status of blade data utilization:

- **Planning:** The blade data extract is utilized to plan the works that need to be done during the repair season based on the finding technical categorization. This data extract is limited to the categories mentioned above, and no further evaluation is done.
- **Recording and Claims:** The blade data extract from new turbines is separated per Windpark to be communicated to the relevant stakeholders. It is also evaluated once in order to spot defects with a root cause that is claimable from other departments, considering solely repair costs.
- **Cost Estimations:** The blade data extract has the total repair time for each finding, and utilizing the total hourly rate per subcontractor it is possible to estimate

costs and forecast a seasonal budget. Still, the calculations done for each of the new windparks takes into account the total repair times as cost impact, without considering future stand-down cost implications into the claim process from the previous point.

Therefore, these are the two main areas of opportunity regarding blade data utilization:

- **Findings' Analysis:** Since the blade data is already into the system, there is the possibility to apply new methods of data evaluation to identify trends, aiming for better work planning and feedback back to other departments for continuous improvement.
- **Liquidated Damages Estimations:** As mentioned, the cost impact estimation of findings that have claimable root causes simply considers the repair cost itself, but considering the repair will happen during the Service contract, there will be Liquidated Damages (LDs), penalty payments to customers for lost availability and production, leading to additional costs to the Service department.

Furthermore, in order to assess the best methodologies to address the aforementioned areas of opportunity, there needs to be a solid understanding on how other departments utilize data, seeking for tools and methods successfully implemented to integrate them as a standardized process for the blade service data management as well.

3.4 Current Blade Manufacturing Process

Nordex has several blade manufacturing facilities around the globe, such as in Spain, Turkey, India, Mexico and Brazil. Most of them are authorized 3rd party factories, but the one located in Lumbier, Spain is part of Acciona Group, which merged with Nordex in 2016. Due to its closeness with Nordex, it was possible to visit their factory premises in September 2024 with the objective of having a real-life experience with the blade manufacturing processes, getting to understand their methods, challenges and opportunities to keep improving their production line.

Having a clear picture of the blade components from section 3.1, the list below presents the streamline process of blade manufacturing, it exclusively been a general and representative record without any specifics from the manufacturer.

1. Cutting glass fiber fabrics
2. Manufacture of spar caps and shear webs
3. Laying of glass fiber fabrics on shells
4. Placing of spar cops and shear webs
5. Shells bonding and blade release
6. Edge cutting and wet lamination

7. Post-curing
8. Machining and assembly of bolts
9. Priming for painting
10. Painting and balancing

As in every industry, quality control and assurance play a crucial role in ensuring that each blade meets strict performance, safety, and durability standards. Given the massive size and unique composite structure of blades, even minor defects can lead to reduced efficiency or failures when the blade is in operation. To prevent such issues, manufacturers implement rigorous quality control and assurance measures at various stages of production.

These processes are designed to monitor the quality of materials, control each manufacturing step, and verify that finished blades meet specifications before they are deployed. Instead of debriefing general quality control and assurance methods, a specialized recap was done during the visit on methods that address defects spotted in blades manufactured before 2023 - meaning them been an improvement driven by identified deviations from previous years.

1. **Reinforcement layers in the Trailing Edge (TE):** During the laying of fibers, there are additional layers placed across the TE, from DF7 to DF37 (Distance from Flange) which means starting 7 meters from the root of the blade for 30 meters.
2. **Surface integrity preservation measures:** During the infusion process, two vacuum bags are utilized for preventing any failure across the infusion area, such as resin leakage or depressurization. Additionally, workers can only wear socks when walking on the blade to avoid any holes when preparing the surface.
3. **Multi-stage Anti-icing System (AIS) testing:** The AIS goes through several checks to ensure its correct functioning throughout the different manufacturing stages. For example, workers conduct three thermal inspections with drones, as well as three current checks. Ensuring the correct functioning of this system before delivery is crucial as its post-factory repair is heavily demanding.

Additionally, there were two particular approaches in the factory itself that are valuable to highlight.

1. **People, Health and Safety, Quality, Delivery, Costs (PHQDC):** According to a factory representative, this approach profoundly impacts by creating a holistic framework to drive operational excellence. Its main target is to ensure productivity through efficient use of resources, enabling higher output with minimal waste. Overall, this serves to align all operational pillars, promoting continuous improvement and long-term resilience in the manufacturing.
    - People: focus on fostering a skilled, engaged workforce and cultivating a positive workplace culture, recognizing the motivated employees are essential to efficiency and innovation.

- Health and Safety: prioritize a safe work environment by minimizing hazards and ensuring compliance with safety regulations, ultimately protecting workers and reducing downtime from accidents.
- Quality: commit to producing products that consistently meet or exceed customer/internal expectations, integrating quality control throughout production to prevent defects and build trust.
- Delivery: ensure reliable, timely delivery of products to customers by optimizing workflows and minimizing delays, which enhances customer satisfaction and competitiveness.
- Costs: manage expenses effectively by reducing waste, improving efficiency, and maintaining cost control, which contributes to profitability without compromising other values.

2. **Defects documentation:** In the production line, there is a tracking board for defect documentation, specifying their location and hours spent on the repair, throughout the year. This practice is crucial for ensuring that issues are addressed promptly in a clear and organized manner, while keeping a record of quality deviations to identify recurring ones. By pinpointing the exact location of each defect, workers can quickly locate problem areas, minimizing and streamlining repair efforts. Also, tracking the hours spent on repairs, allows the stakeholders to assess repair times which can reveal patterns in recurring issues and help improve future practices. Overall, this board serves as a powerful tool for enhancing quality control, and engaging workers to sustain high operational standards. The Figures below are representative illustrations (with random values) from the tracking board graphs, aiming to showcase the distinct visual aids for understanding the data and identifying trends.

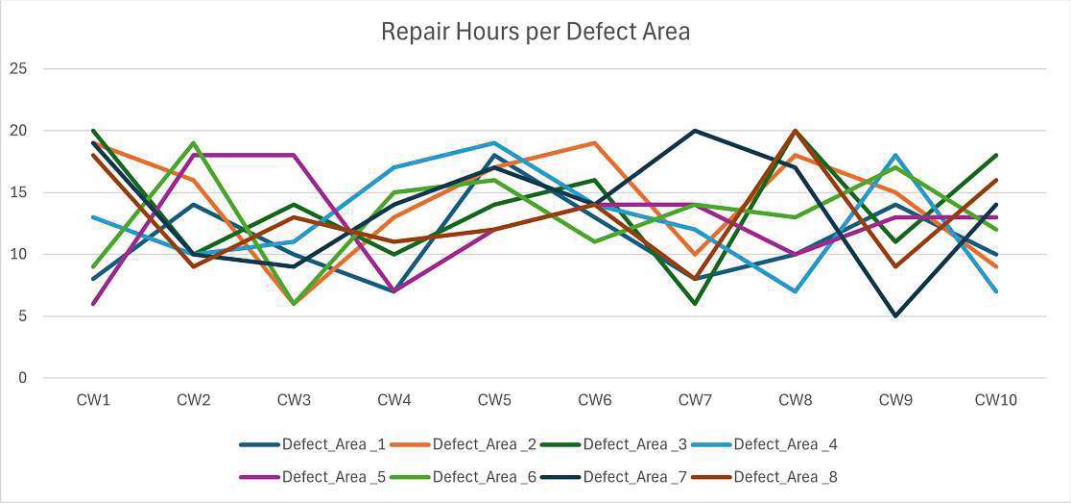

Figure 11: Representative Line Graph for Repair Hours per Week for Defects

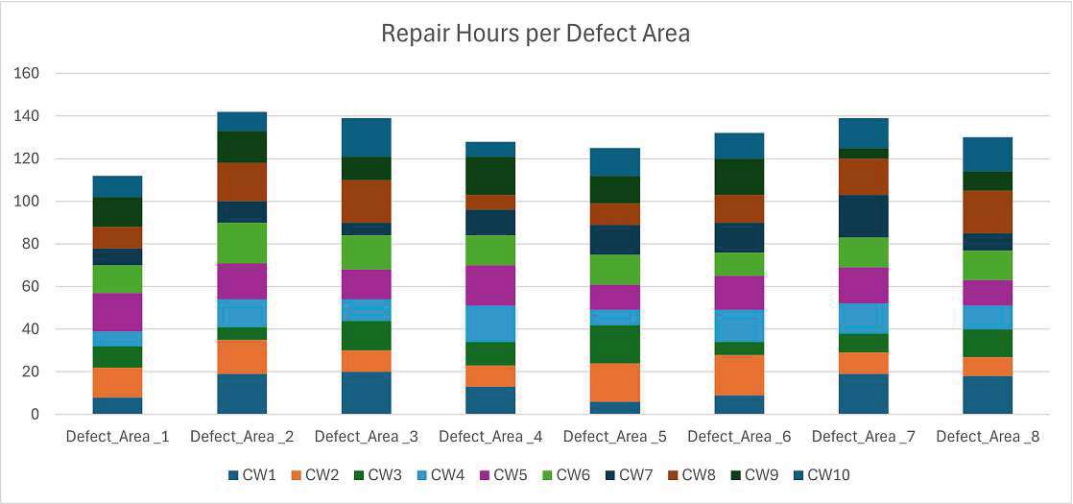

Figure 12: Representative Bar Graph for Repair Hours per Defect per Week

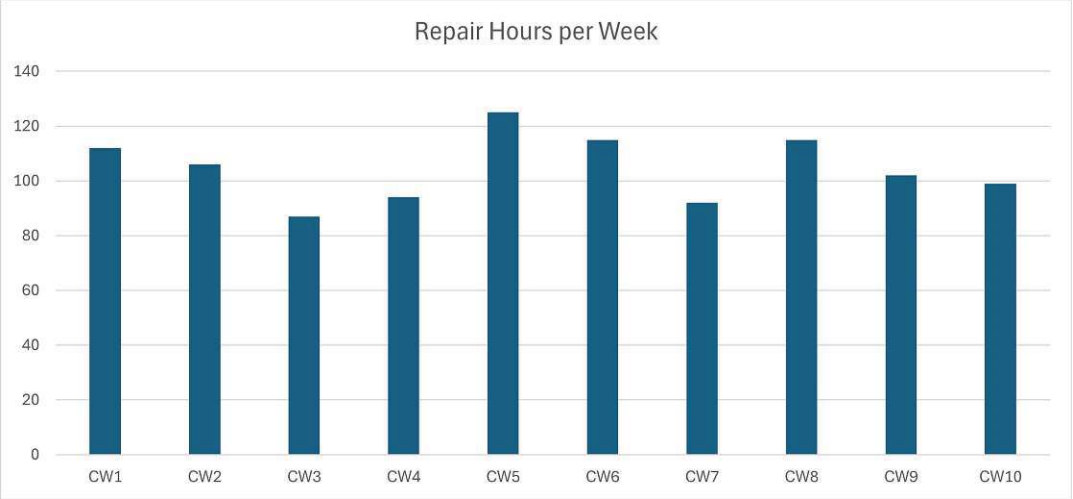

Figure 13: Representative Bar Graph for Repair Hours per Week

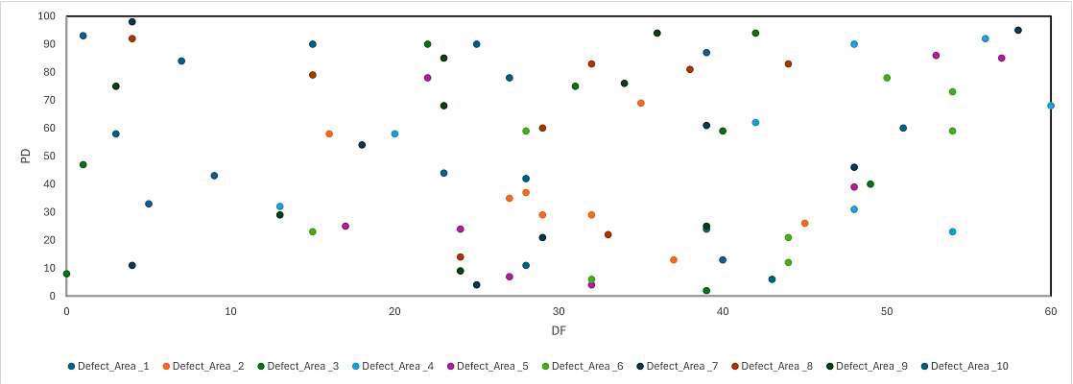

Figure 14: Representative Scatter Graph for Defects Location Across the Blade

Firstly, PHQDC can be closely related to some Total Quality Management (TQM) concepts. The "People" focus utilizes Total Employee Involvement as a resource to foster a positive and efficient workplace through recognition as a motivation driver. Also, there is a strong connection with continuous improvement for customer satisfaction, leading to an ultimate customer focus on the process of implementing techniques for better quality.

Secondly, the defect visualization from Figure 14 is highly relevant for the aforementioned area of opportunity on findings' analysis, as it can visualize recurrent "damaged" areas and allow a better feedback to be sent to the relevant stakeholders when needed. These ideas will be taken into account when developing the implementation strategies to reach the project objectives and have meaningful results' analysis to draw conclusions.

3.5 Current Post-installation Blade Quality Check and Communication Process

When a wind park is built, it is a project that is handled by the department of Project Management (PM). Once they are installed, the Commissioning department works on, precisely, commissioning the turbines to be able to handover the wind park to the customer and the Service department, who will take care of maintaining the turbines in optimal conditions. Referring specifically to blades, the Nordic Blade Team makes overall blade inspections to assess the conditions of the blades when receiving the wind park from the PM department. The Figure below visualizes this process, highlighting actions and departments involved.

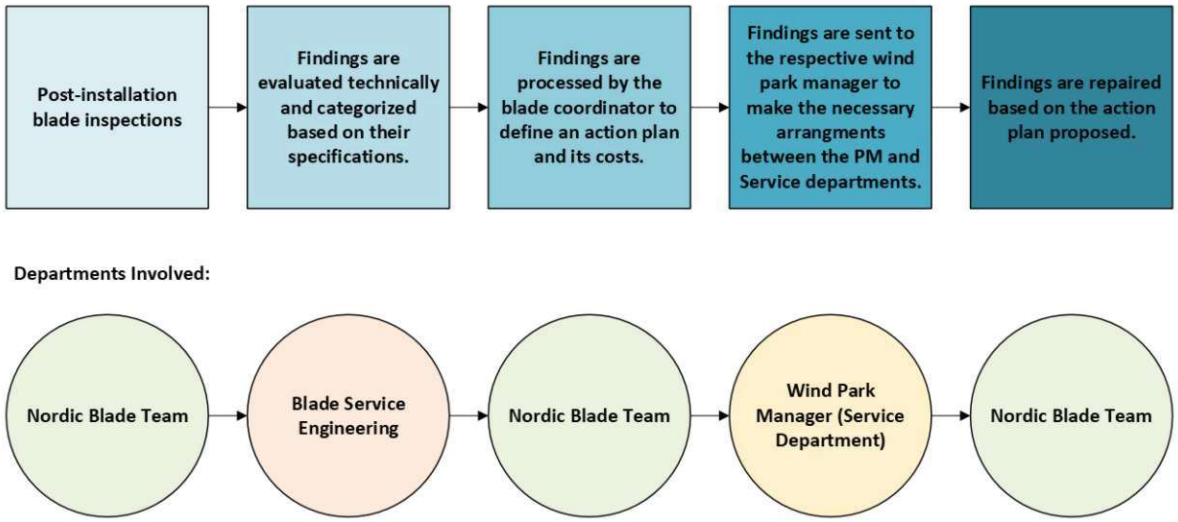

Figure 15: Current Communication Process for Post-Installation Findings

The diagram above displays every step of the communication process for post-installation findings, where the key actions from every department involved are described. This representation shows that the findings' communication lies between first-hand stakeholders, without any oversight or previously-involved department being informed with relevant data or actions to be taken. This communication process has effectively worked to plan and coordinate the necessary blade works, sharing relevant feedback to those first-hand stakeholders. Focusing on the third step in the diagram, the Blade Team extracts data with similar categories to the ones mentioned in Section 3.3, but adding a couple of columns for additional information on action plan and costs, which are relevant to the wind park manager. The extracted data would contain the following:

- Ticket Number
- Finding ID Number
- Windpark
- Turbine Number
- Blade Number
- Finding Category
- Quality Deviation Type
- Subcomponent Affected
- Deviation Size
- DF - Start
- DF - End
- PD - Start
- PD - End
- Repair Instructions
- Total Repair Time
- Root Cause
- Comments (from technical department)
- Planned for (referring to the year it should be addressed)
- Status (if any actions taken)
- Estimated Cost

This data then is synthesized by utilizing the pivot table function from excel to summarize repair times, costs, and filter data based on the year that the findings should be addressed, category, status, subcomponent affected, quality deviation type and root cause. The figure below exemplifies the final template utilized to communicate the findings.

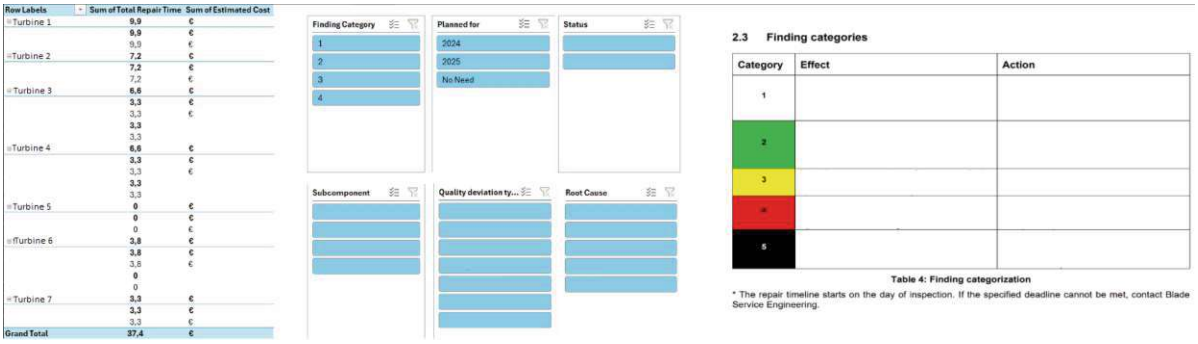

Figure 16: Template for Findings' Communication

The template shown is displays accurately the costs and time needed to repair the deviations, with a detailed explanation on the finding's categorization to define an action plan. However, the current template utilized serves the purpose of communicating the relevant information to the wind park manager, but does not have any further evaluation or format to be shared with other relevant departments. Considering the current communication process and template, the following areas of opportunity were identified.

- **Extended Communication Process:** The current communication process provides feedback restrictively to first-hand stakeholders, hence an improved process could be studied for meaningful share of data to other relevant departments, aiming for continuous improvement strategies.
- **Dynamic Template:** The template in use is restricted to provide feedback to the wind park manager, without any flexibility or adaptability to share information with other departments, such as claim management or Global Quality. Therefore, an improved reporting platform and template can be used to present distinct data for each department without the need of increasing workload.

Furthermore, in order to understand the best communication processes and channels for addressing the areas of opportunity identified, there needs to be a detailed study that collects feedback from each department to spot their needs and interests. That study would lead to a repeatable and scalable process that enhances continuous improvement as a standard in the organization.

3.6 Implementation Strategies

With the proper consideration of the current status of the company in the areas described, as well as the relevant literature presented, several processes can be followed to

utilize them as a base for working on the project objectives. The points below describe the four main strategies that will be conducted in order to create useful outcomes for each objective (from section 1.3).

- For objective 1, the data from post-installation blade inspections of turbines installed in 2023 will be extracted from the system, to do a data analysis cost forecasting (as described in section 2.5.5) with the purpose of identifying costs and their impact on labor and operational levels, displaying an amount that aims to demonstrate the significance of the research objectives of this project.
- For objective 2, a specialized methodology will be proposed for defect identification and communication after manufacturing, showcasing certain criteria that should be taken into account based on the Service department's historical data on blade defects, supported by the analysis from objective 1. Additionally, this methodology will touch upon TQM strategies for total employee involvement, as mentioned in section 3.4 with the PHQDC approached utilized in the factory.
- For objective 3, the communication process for post-installation findings (from section 3.5.2) will be improved in such a way that its output results on meaningful feedback for continuous improvement in blade manufacturing and installation, utilizing already-implemented graphics, such as Figure 14, for an efficient review. Nonetheless, this process will consider concepts developed in objective 2, for creating accountability and responsibility for feedback from the stakeholders involved.
- For objective 4, tools will be proposed, considering historical data analysis and bottom-up estimation techniques, for picturing the cost implications of blade quality deviations for a later efficient use of resources. This objective should act as a base for further, detailed studies on what would be priority areas to improve, considering the outcomes from the project objectives and factors outside of the scope of reach of the study itself.

With these strategies settled, individual studies were done for each objective, aiming to resemble their significance, validity and viability within the company. The results section shows the steps and relevant information utilized to draw conclusions, delving into the reliability of the inputs and outputs, pinpointing strengths, weaknesses and opportunities for further studies.

4.0 Results and Findings

This section presents the findings for each of the project objectives, utilizing multidisciplinary approaches to assess the reliability of the results, to ultimately expand on the significance, validity and viability of the suggestions made.

4.1 Economical and Operational Impact of Blade Quality Deviations on the Turbine Fleet Installed in 2023

As previously mentioned in the implementation strategies, the economical and operational impact of blade quality deviations on the turbine fleet installed in 2023 will be studied utilizing the data analysis cost forecasting, to express the cost impact of those deviations. Additionally, this study delves into the root causes for deviations to identify cost-claimable ones, which means money that could come back to the Service department, as well as touching upon the customer-side as the theory of Total Quality Management (TQM) describes.

To start, all the values in this study are expressed in terms of factor $\boldsymbol{N}$ rather than the exact number, to keep the underlying relationship with the company's data confidential. The baseline factor $\boldsymbol{N}$ is a 4-digit value known by the author and relevant stakeholders, but still it serves as a reference for the purpose of the study as its coefficient showcases the magnitude of the data presented.

Firstly, the findings from the inspections on the turbine fleet installed in 2023 was extracted from the system, with similar categories as the mentioned ones in section 3.3, but excluding unnecessary data for the cost analysis. Therefore, the extracted data contains the following categories for every finding.

- Ticket Number
- Finding ID Number
- Windpark
- Turbine Number
- Blade Number
- Finding Category
- Quality Deviation Type
- Subcomponent Affected
- DF - Start
- PD - Start
- Repair Instructions
- Total Repair Time
- Root Cause

It is relevant to explain how some of those categories will be utilized. The finding category, quality deviation type, subcomponent affected and repair instructions are meaningful to have a technical understanding of the finding, to then assess what are the the requirements for the repair process, leading to an appropriate total repair time handling. The root cause will be utilized to review on which stage the deviations could have happened, helping to conclude if they are claimable damages or not. The DF and PD are simply for reference, and will be utilized in other sections.

Secondly, the cost of the repair needed, referring to labor costs, is estimated utilizing a representative value obtained through a calculation with the Total Hourly Rate Calculator from Figure 10. Since there are two main repair access methods, with two distinct costs, depending on the technical specifications of the repair instructions, costs were assigned accordingly. Thirdly, the cost estimation for Liquidated Damages (LDs) is calculated with the same technical criteria, but with an average daily LD cost, which was obtained from one of the project managers of the company. The summary of the findings with their corresponding estimations is shown in the table below, having them clustered by windpark.

Windpark	Sum of Cost of Repair (€)	Sum of Cost of LDs (€)
Windpark 1	38,7 N	11,5 N
Windpark 2	21,9 N	6,5 N
Windpark 3	5,7 N	1,7 N
Windpark 4	30,8 N	9,2 N
Windpark 5	248,0 N	81,3 N
Windpark 6	30,6 N	16,8 N
Windpark 7	60,8 N	18,1 N
Windpark 8	14,4 N	8,7 N
Windpark 9	131,1 N	39,1 N
Windpark 10	1044,5 N	330,0 N
Windpark 11	56,7 N	23,4 N
Windpark 12	11,3 N	3,3 N
Windpark 13	201,7 N	106,0 N
Total	**1896,3 N**	**655,7 N**

Figure 17: Costs of Repair and Incurred LDs per Windpark

The table in Figure 17 displays the sum of costs for the repairs themselves, as well as the LD costs that those cause. Solely considering the data presented, it can be seen that blades with an installation period lower than a year already present significant amount of deviations, which in their vast majority should not be there. The straightforward answer to the the first project objective would be that the blade quality deviations present on the turbine fleet installed in 2023 cause an labor cost loss of 1893.3$\boldsymbol{N}$ alongside 655.7$\boldsymbol{N}$ in operational losses. These numbers represent a huge economical impact for the company, caused by almost new blades, which sounds arguable as a new blade should be almost deviation free. The data presented in Figure 17 is accurate as it takes data collected directly from the field, and the cost estimations follow a company standard process.

However there are certain points to be considered. First, the data extracted corresponds to every single finding located on the blades, meaning that they have their individual time of repair and costs. Still, it is often the case that several of the deviations found can be repaired at once, which would reduce the cost according to the total number to be done in one repair. Additionally, the LDs costs are strictly proportional

to the time the turbine is stopped for the repair, hence if less repair time is needed, the lower the cost of LDs is. Therefore, if the planning of the repairs is executed efficiently, the costs shown in the table could reduce by a 20 to 40 percent, depending on how many single findings can be repaired at once.

On the other hand, it is also relevant to explore what are the root causes of each deviation to categorize them and find which is the stage that should be a primary focus of improvement. Additionally, depending on the root cause identified, it would be possible to claim back the costs incurred if there is a clear data to support that. The table below summarizes the root causes with the corresponding costs as in Figure 17.

Windpark	Sum of Cost of Repair (€)	Sum of Cost of LDs (€)
Root Cause 1	343,1 N	102,1 N
Root Cause 2	909,7 N	275,0 N
Root Cause 3	14,2 N	4,2 N
Root Cause 4	15,4 N	6,4 N
Root Cause 5	15,6 N	9,7 N
Root Cause 6	276,8 N	153,4 N
Root Cause 7	7,4 N	2,5 N
Root Cause 8	303,7 N	99,2 N
Root Cause 9	10,3 N	3,1 N
Total	**1896,3 N**	**655,7 N**

Figure 18: Costs of Repair and Incurred LDs per Root Cause

As mentioned, the root cause is often utilized to spot the stage at which the deviation was caused, and to assess the possibility for the Service department to claim the incurred costs to other departments or third parties, since they should not take those costs into their Profit and Loss statements. Still, each root cause is unique and not all of them are "claimable", hence the table below highlights the root causes that are possible to be claimed.

Windpark	Sum of Cost of Repair (€)	Sum of Cost of LDs (€)
Root Cause 1	343,1 N	102,1 N
Root Cause 2	909,7 N	275,0 N
Root Cause 3	14,2 N	4,2 N
Root Cause 4	15,4 N	6,4 N
Root Cause 5	15,6 N	9,7 N
Root Cause 6	276,8 N	153,4 N
Root Cause 7	7,4 N	2,5 N
Root Cause 8	303,7 N	99,2 N
Root Cause 9	10,3 N	3,1 N
Total	**1896,3 N**	**655,7 N**
Total of Claimable Costs	**1527,2 N**	**540,8 N**

Figure 19: Claimable Costs due to the Identified Root Cause

As it can be seen in Figure 19, about 80 percent of the deviations costs are claimable due to their respective root cause. A root cause is considered as claimable only when there was an irresponsible handling of the blade by the other department or third parties. Nonetheless, processing the claims is not easy due to the level of detail that they should contain, as well as the guarantee period established in the agreements with all the relevant stakeholders. Some of the root causes could immediately be claimed since the root cause provides enough detail by itself, but there are others that require deeper technical assessment and legal frameworks to be applicable. The figure below splits the root causes based on their actionability.

Immediately Claimable to Other Departments/3rd Parties

Windpark	Sum of Cost of Repair (€)	Sum of Cost of LDs (€)
Root Cause 3	14,2 N	4,2 N
Root Cause 4	15,4 N	6,4 N
Root Cause 6	276,8 N	153,4 N
Root Cause 8	303,7 N	99,2 N
Total	**610,0 N**	**263,3 N**

Claimable After Analysis to Other Departments/3rd Parties

Windpark	Sum of Cost of Repair (€)	Sum of Cost of LDs (€)
Root Cause 2	909,7 N	275,0 N
Root Cause 7	7,4 N	2,5 N
Total	**917,1 N**	**277,4 N**

Figure 20: Claimable Costs Split by Actionability

Figure 20 effectively splits the costs based on their claim actionability. which demonstrates that only 40 percent of the total claimable costs can be processed immediately. As mentioned, to be able to claim the remaining 60 percent, there are certain technical specifications that need to be reviewed to then proceed with the corresponding claims. To do so, there must be an effective communication process of findings for prompt actions. As described in shown in Figure 15, the current communication process for post-installation findings is limited to first-hand stakeholders rather than aiming for a strong feedback strategy to other relevant departments.

Before digging deeper into other topics and concluding the first objective, a recap of the debriefed information is displayed in the following points and figures.

- The potential economical and operational impact of blade quality deviations on the turbine fleet installed in 2023, based on their technical evaluation and specifications, adds to € 2,552$\boldsymbol{N}$, divided in € 1896.3$\boldsymbol{N}$ of labour costs and € 655.7$\boldsymbol{N}$ of liquidated damages (operational downtime).
- The root cause analysis of each deviation is significant to understand at which stage the deviations happened. Based on the data collected, root causes 1, 2 and 8 are relevant to be studied to identify areas of opportunity to reduce deviations during their corresponding stages.
- Knowing the root causes, it is possible to assess if the costs incurred by the repair of the quality deviations are claimable to the respective department or third party that was in charge of the blade at that stage. As shown in Figure 19, 80 percent of the costs are claimable, hence it is key for an improved communication process of the findings to be established. Figure 21 shows the claimability of the costs and actionability of those claims.

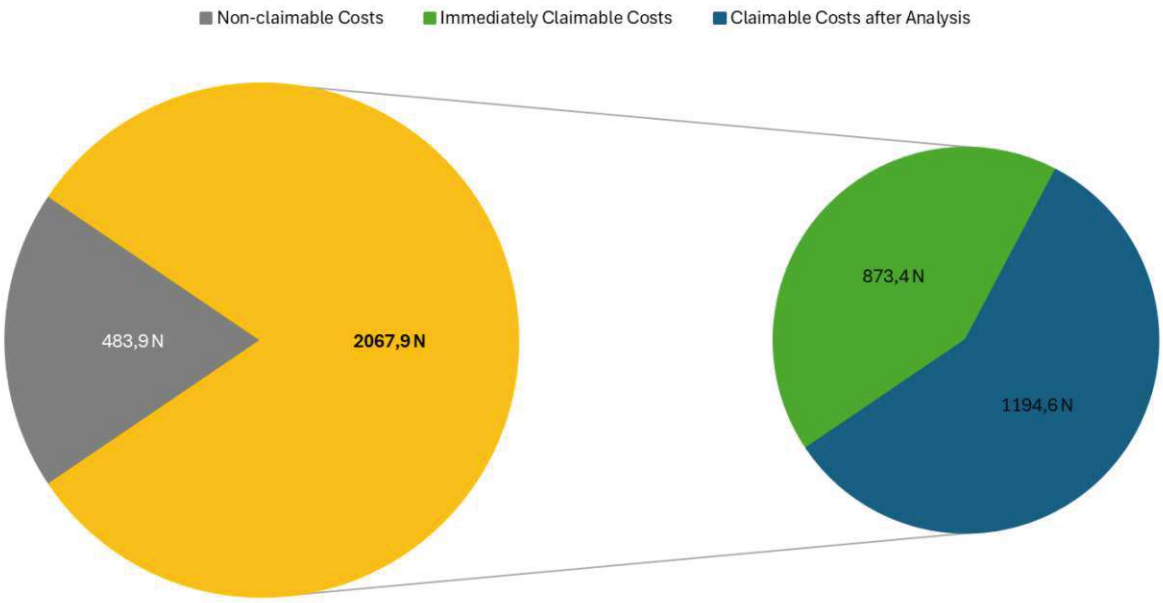

Figure 21: Claimability of Costs from deviations on 2023-installed blades

This is highly relevant since the costs' impact from point 1 could be eased for the Service department with the correct infrastructure and processes to realize claims promptly.

- The data presented demonstrates that there are high repair costs and operational penalties coming from "recently" installed blades, which does not match with the expected quality and lifetime of new blades. There must be a reinforcement in quality tracking and assurance in the stages identified through the root causes, while an improved communication process to promptly communicate the findings and necessary details to process claims and reduce unnecessary expenses for the Service department.

With a clear picture of the economical and operational impact of blade quality deviations on the turbine fleet installed in 2023, it is possible to assess how this affects in a business level. The concept of customer focus, from section 2.1.1, suggests that the customer defines quality, hence organizations should always try to meet the expectations of their customers, or even exceed them (Khyat et al., 2020). Based on insightful interactions with customer representatives, it has been expressed that they would expect to have minimal, aesthetic defects on their recently installed blades rather than defects that require extensive operational downtime. Considering this, there should be a strong focus on point 2 from the list above, in order to produce an action plan to overcome one of the pain points of the customers. As Bhujabal and Swain (2020) suggest, a robust customer-centric focus elevates the level of satisfaction, which results in high extents of customer loyalty and retention. Just as section 2.2.2 highlights, continuous improvement is fundamental for maintaining customer satisfaction, which should impulse a culture that is

responsive to steady streams of feedback. Additionally, customer retention is key for wind turbine companies to keep building and placing their products in known regions, serving as a base for expansion plans.

Wrapping up, it is important to address the significance, validity and viability within the company of the points made. This part of the study is significant as it recognizes the strong data collection system that the Service department of the company has, to create historical records of the blades since they are handed over to them. However, its significance also resembles the need for additional data processing and management techniques for cost reduction, quality enhancement and customer satisfaction. The points made can be considered valid since all the conclusions drawn come straight from the data collected through the inspections, including the technicalities and inputs from relevant stakeholders. Similarly, those conclusions consider the current state of the company's processes discussed in section 3, meaning that with the correct action plan, improvement measures can be implemented in a viable and feasible manner.

Looking into building up arguments for future actions, the following objectives aim to propose processes that could serve as a baseline to initiate developments for continuous improvements in identified weak points, taking into account the strengths of the existing procedures, and opportunities they bring for the company's amelioration plan.

4.2 Methodologies for Deviation Identification, Evaluation and Tracking

As discussed in the previous section, the root causes from the quality deviations found during post-installation inspection permit the identification of areas where actions need to be taken to not only spot defects, but to evaluate them promptly and track them accordingly. Because of that, a multi departmental methodology should be established, specialized on blade quality management with distinct sources of input.

The company is structured in such a way that several departments are involved in the blade manufacturing process. Therefore, it is possible to imagine a multi departmental approach where each of the stakeholders is accountable for communicating any identified quality deviations for its optimal tracking and resolution. The figure below provides an overview on the steps of blade handling, with their corresponding departments highlighted.

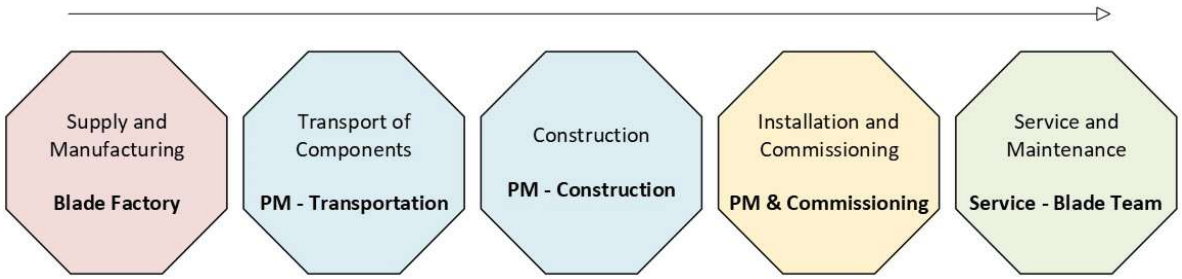

Figure 22: Flow of Responsibility for Blades' Handling

The steps and departments showcased in Figure 22 are directly involve in the hand-

ling of blades, starting from the manufacturing itself, to the transportation, construction, commissioning, to end up handed over to the Service department for regular maintenance and optimal performance. Since it would be counterproductive for every single department to have distinct guidelines on blade quality, there are also oversight departments which deliver quality specifications that are applicable at every stage of the process, with their respective adaptations and particularities. These departments would be incorporated into the flow chart as shown in Figure 23.

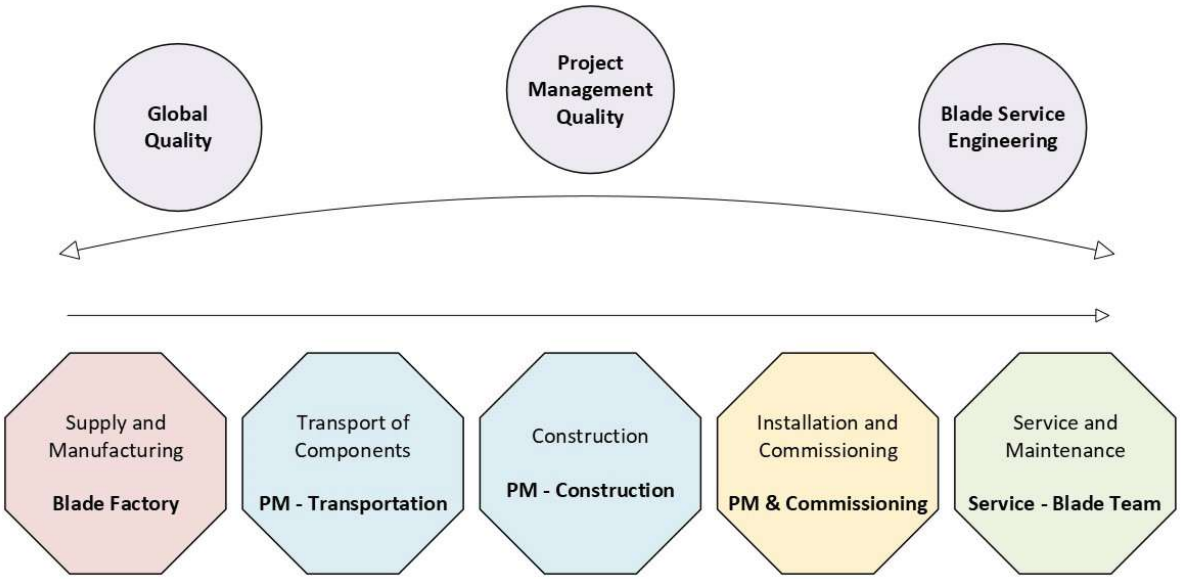

Figure 23: Flow of Responsibility for Blade's Handling and Oversight Departments

Considering the multi-departmental process displayed in the Figure above, to be able to implement successful methodologies for the quality deviation identification, evaluation and tracking there must be a rigorous process of communication with the necessary tools for the correct documentation. Through an intensive workshop on blade practices, information regarding current and developing processes was collected in order to understand the base at which the methodologies to be proposed could start. With respect to current processes for quality deviation identification, evaluation and tracking, it has been raised up that every department has its internal recording method that is only shared with its first-hand stakeholders. The data collected is processed in the preferred method of the department rather than a unified platform for recording the findings and actions. Nowadays, the oversight departments are working on a unified method of data collection, evaluation and tracking with a strong appeal to transparent communication. Still, they have identified three main challenges:

1. Which is the best platform that would fit every department's needs?
2. Up to what extent does departments need to be communicated of previous actions taken on the blades?

3. Lack of standardized communication channels between departments.

Considering those challenges, this study focuses on how creating methodologies to address the identified setbacks. Before addressing each challenge individually, a possible multi-departmental defect tracking process was created, shown in Figure 24.

The process displayed in the Figure above takes into account the departments from Figure 23, to then describe the actions needed when a defect is spotted since the factory, expanding into every input from the different departments, ending up with solid knowledge on what has been done to the blade. This diagram visualizes one of the many possible processes to be implemented, however the three uncertainties mentioned need to be resolved.

With respect to challenge 1, the best platform would be a tool that allows constant recording of information on a blade level. Blade level recording is specifically mentioned since departments such as PM, Commissioning and Service, track the works done per turbine. However, this platform should be adaptable to the needs of every department, which are extensive. At the moment, there is no response on the best platform, but collecting feedback from every department would be the firs step to then assess which platform offers the most development opportunities. To gather information for challenge 2, several discussions took place with blade experts from the PM, Service and Blade Service Engineering, which brought to light several perspectives to draw conclusions. The straight-forward answer would be that departments need to be communicated everything. However, the most realistic answer is that there is no need to explicitly communicate every single incident, but rather to have all the data available in a single source of information in case it is needed, or deeper analysis needs to be done, by Global Quality as an example. This leads again to solving challenge 1, but it is definitely relevant to consider this information in the development phase of the platform in question. Ultimately, challenge 3 relates again to challenge 2. There should be a standardized communication channel for departmental exchange of information and notifications, but there is no need to pinpoint and communicate individual incidents all the time. Instead, the already implemented documentation should serve as a primary communication channel. For example, when a blade goes from one department to another, there are handover guidelines and templates to be completed. Then, those should incorporate a list of actions taken and how to track them in the platform. Therefore, answering challenge 3, a documentation platform could be instated where all the related handover guidelines and templates are available, but that efficiently links them to the platform for detailed information.

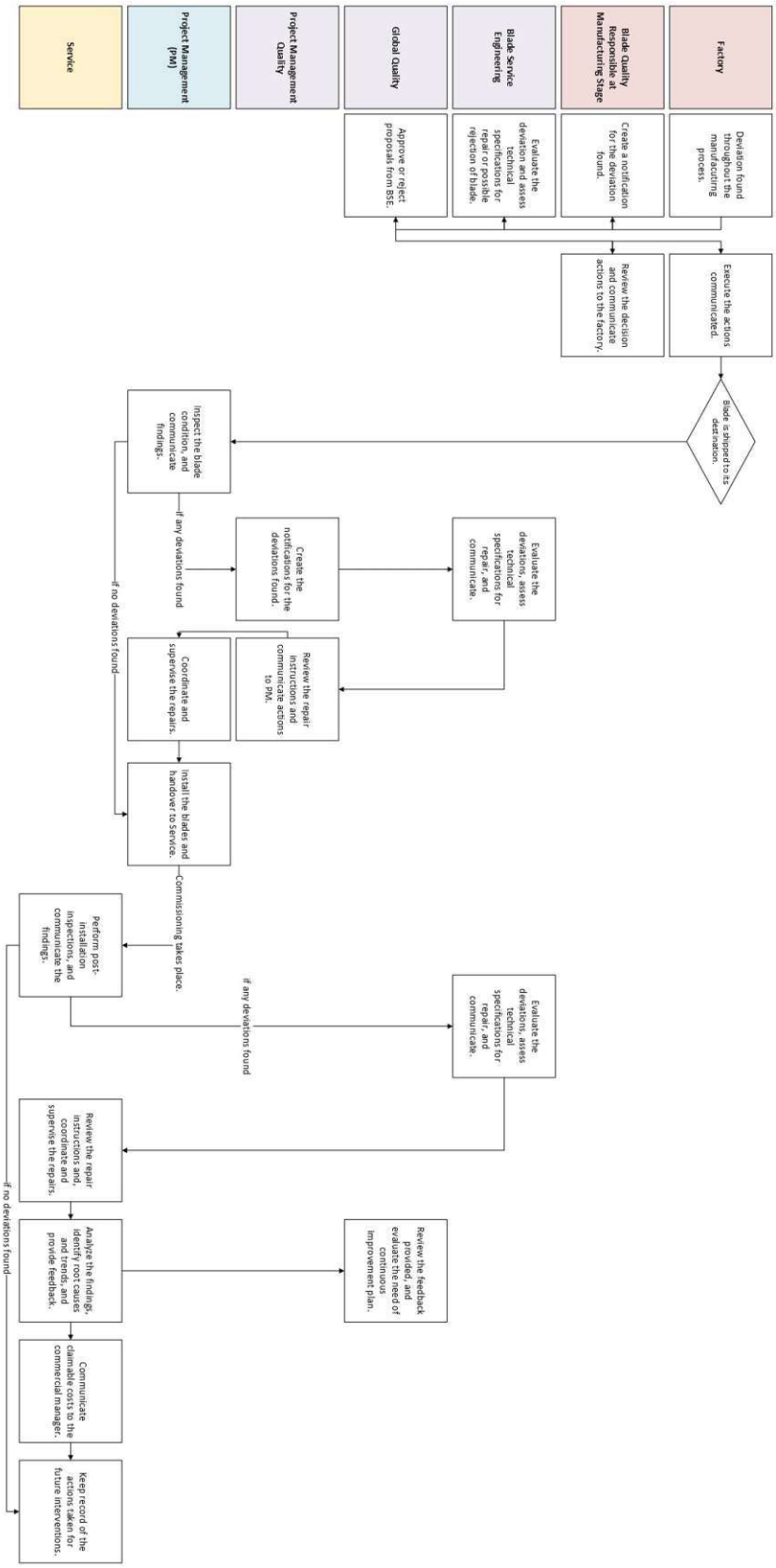

Figure 24: Possible Multi-departmental Defect Tracking Process

Considering the ideas previously mentioned alongside the proposed tracking process diagram, it is possible to imagine the implementation of a method similar to a Digital Product Passport (DPP). A DPP refers to a digital record that provides detailed information about a product's lifecycle, including its materials, production process, usage, and end-of-life options. It often improves transparency, traceability, and sustainability in supply chains (King, M. et al., 2023). According to the article by King (2023), DPP are typically framed as a solution to the lack of consistent and precise information flow about resources, products and processes, as well as to track and trace instruments for unique product information. This method requires, again, a sustainable and adaptable platform where every stage is able to record the necessary information. However, this concept provides a notion on how the system could be developed. By having inputs at every blade handling stage in a digital record, it would be possible to assess and trace back and forth any actions taken or to be taken based on the product's initial guidelines. As any other methodology, this approach needs to go through a collective, multi-departmental evaluation process for deciding on the most suitable and feasible process, considering the available resources of the company.

There are dozen of methodologies that can be found, adapted, and utilized by organizations. However, the turning point on its viability lies on the engagement the responsible people of inputting the information has with the whole process. One of the primary focus should be on implementing a Total Employee Involvement (TEI) strategy alongside the method itself. As presented in section 2.1.2, TEI aims to empower and encourage staff to take responsibility for the quality of their work and make suggestions. TEI also looks into promoting accountability to achieve better goals, which in the context of this study, would mean proactivity to effectively record and communicate incidents promptly, understanding their value and impact in a long-term perspective. Due to the diverse human factors that are involved in the process, it is key to find ways to keep employees engaged and motivated, and based on a workshop on collaboration, the following techniques were identified.

- **Empowerment through participative decision-making:** this refers to actively involve employees in decision-making processes, particularly in areas that impact their work. When employees are given a voice and their opinions are valued, they feel a sense of ownership and accountability for outcomes. As a result, employees feel trusted and responsible for contributing to the organization's success, leading to a culture of collaboration.

- **Focus on psychological safety and professional development:** this creates opportunities for employees to enhance their skills and knowledge while fostering an environment where they feel safe to express ideas, ask questions, and take risks without fear of embarrassment or punishment. Psychological safety enables employees to bring their whole selves to work, promoting creativity, collaboration, and accountability. When paired with professional development, it reinforces the message that the organizational values both, their growth and their well-being. Employees feel respected and secure in their workplace, which boosts their confidence to take responsibility, contribute ideas, and collaborate effectively with

others. This nurtures TEI and reinforces a culture of mutual trust and growth.

- **Recognition and continuous feedback:** this looks into implementing systems for recognizing achievements and providing constructive feedback consistently. Recognition for good work reinforces positive behavior, while constructive feedback helps employees grow and take responsibility for their roles. Consequently, employees feel valued and motivated, and the culture of accountability grows as they understand their contributions and areas for improvement.

The techniques listed delve into creating a safe environment of accountability, incorporating stimuli that trigger positive and effective reactions in the individuals. For example, a similar approach is already utilized in the factory, that serves as a base for a deeper TEI, and it was described in section 3.4 under the PHQDC debrief. The approach described focuses on fostering an engaged workforce and cultivating a positive workplace culture, recognizing that motivated employees are a primary factor on efficiency and innovation. The factory aims to make employees aware of their importance, encouraging them to feel responsible and accountable for not only doing quality job, but to have a continuous improvement mindset. Taking all of this into account, a further study on multidisciplinary methods for deviation identification, evaluation and tracking should be performed to find the most suitable and efficient platform that allows full visibility on actions taken, merging technical and human requirements that foster a conscious and responsible environment of proactive reporting.

Digging into the significance of this study, establishing multi-departmental communication strategies for defect tracking would lead into an environment of constant feedback for continuous improvement, supporting them with the correct tools and employee involvement techniques. The suggestions made are significant due to the current state and development of the aforementioned tracking processes, as well as the identified impact that deviations cause in the Service stage. Having a transparent data collection system with multi-departmental inputs would benefit any future actions needed regarding the blades, either internally or externally. Additionally, this study's is highly valid and accurate to the organization's needs based on the feedback collected from stakeholders and day-to-day data capture, as explained in section 3.1. Having as primary sources the relevant people that are involved with blades in their daily activities is key to validate and reproduce the study in the most convenient matter for positive outcomes. Also, the conclusions drawn on the methodologies proposed for tracking and employee involvement are aligned with the company;s objectives and resources, making the viable and feasible to study their future use and development.

Due to the scope and limits of this study, following sections will be centered in actions and tools to be used by the Service department to efficiently contribute to the methodologies proposed, taking economical, operational and human factors into account. Therefore, the upcoming studies will reveal the opportunities the Service department has to share their knowledge, capabilities and techniques to foster a company-wide continuous improvement environment with steady streams of technical and human feedback.

4.3 Communication Process for Findings' Feedback at Service Department Level

The findings and analysis from the previous sections permit a deeper understanding on the company's needs for improvement. As shown in Figure 24, the Service department is responsible to not only provide and maintain turbines, and blades, in optimal shape, but also to communicate findings and cost impacts to the respective stakeholders promptly. The significance of improved processes of communication is implied on the needs described, and that leads into developing a feedback-based communication process that merges technical and economical data for efficient and unified outputs.

The diagram displayed in Figure 15 concisely presented the Service department's current communication process for post-installation findings, as that is the stage where economical and operational impacts are estimated to finalize the handover to Service. As it was concluded in sections 3.3 and 3.5.2, data is solely utilized for planning, records and estimations within a small group of stakeholders. However, this information should be efficiently communicated as feedback to other stakeholders, having as an example the departments from Figure 23. Considering this, the communication process in Figure 25 was developed for post-installation findings communication.

Figure 25 portrays the actions that the Nordic Blade Team of the Service department should carry out for post-installation inspections and findings, linked to the different inputs and communications that should take place with other departments. This process takes into account the relevant points previously identified through the study, ameliorating the existing communication flow to obtain a greater reach of data feedback.

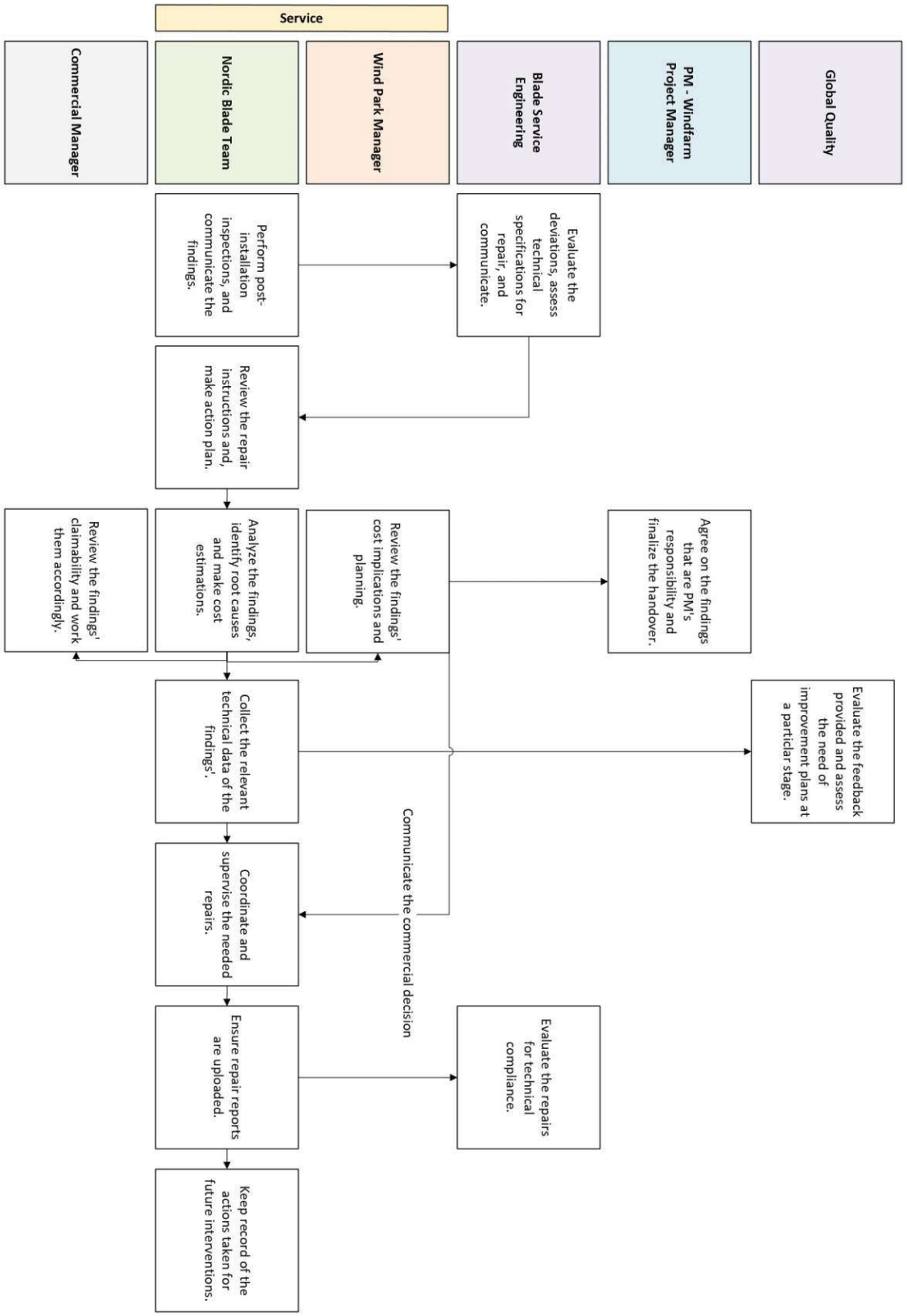

Figure 25: Communication Process for Post-installation Findings

Furthermore, this process is significant because it is possible to replicate and repeat it at any stage where findings are identified and need to be communicated. One of the most important things about process development is repeatability, alongside scalability. Implementing repeatable and scalable processes is key for process standardization, which in the long run bring tangible and intangible benefits to the organization. However, a process should also come with the right tools and resources, which in this case would be effective reporting systems that display only the relevant information to the respective stakeholder. As presented in Figure 16, the template for the communication of findings focuses on feedback for windpark managers, not clearly displaying any relevant information for claim management and global quality, as it would be part of the process developed. Due to that reason, the following templates were developed through Power BI, bringing a visual and interactive summary of the findings, displaying the most important information for every stakeholder. Power BI was chosen as the reporting platform due to its access to live data from the system used for data collection and management.

Figure 26: Interactive Reporting Template for Global Quality

Figure 26 shows the interactive reporting template that would be utilized to provide feedback to Global Quality, displaying representative data for the purpose of the study but that does not demonstrate data from the company. This template is composed by two main sections: a table to debrief every finding's details, and a dynamic scatter graph for defect location which has on top, fields that are filled in when selecting a deviation, to mention its repair status, deviation type, root cause, and repair instructions given by Blade Service Engineering. The table presents the data with the categories listed in section 3.3, which provide all the qualitative and quantitative data required to

make an assessment on the findings. Meanwhile, the scatter graph follows the already implemented system for defect documentation, in Figure 14, which is used in the factory premises. This interactive graph helps to not only spot the location of a finding, but to identify trends and possible focus points that Global Quality should consider for their continuous improvement plans. Also, by having an already implemented method used in other departments, it is easier to leverage feedback and act accordingly.

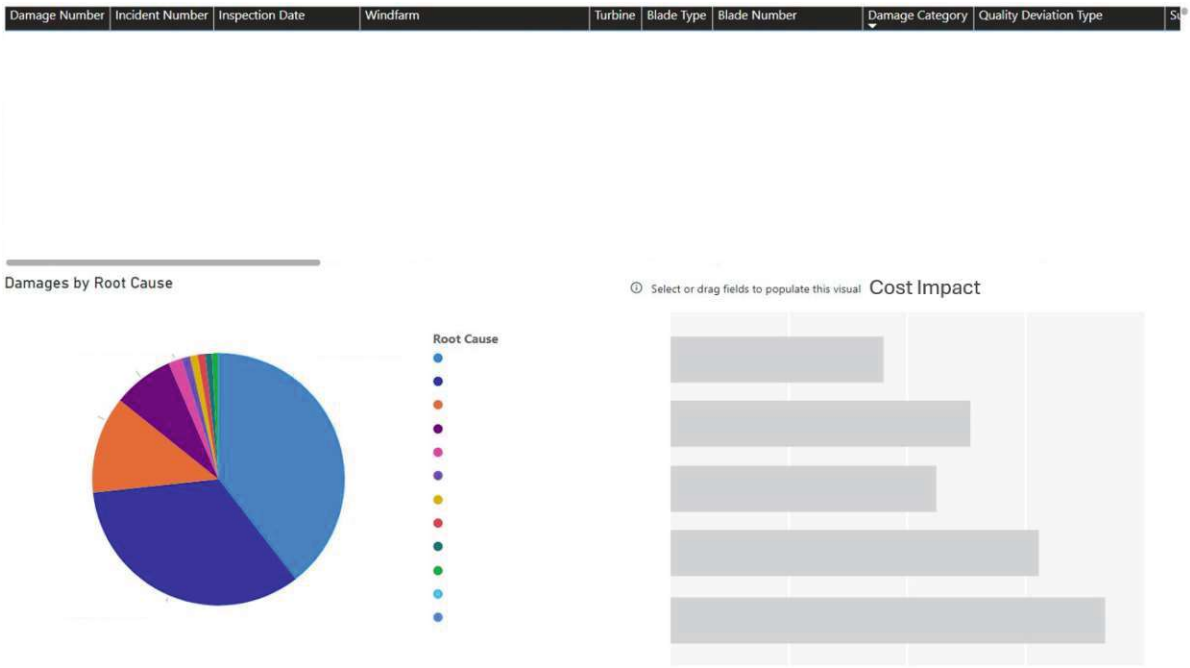

Figure 27: Interactive Reporting Template for Claim Management

Figure 27 shows the interactive reporting template that would be used to provide feedback to the commercial manager for claim management. Similar to the other template, it is composed by a table to debrief the findings, but accompanied by a pie graph that presents the root causes identified and their respective cost impact. As explained in section 4.1, root causes are used to identify claimable deviations. and having a cost impact estimation integrated in the reporting would ease the work for claim management. The efficient display of the technical details and economical impacts arise opportunities for a standardized reporting process where comparisons can be made, and to strongly back up claims if needed.

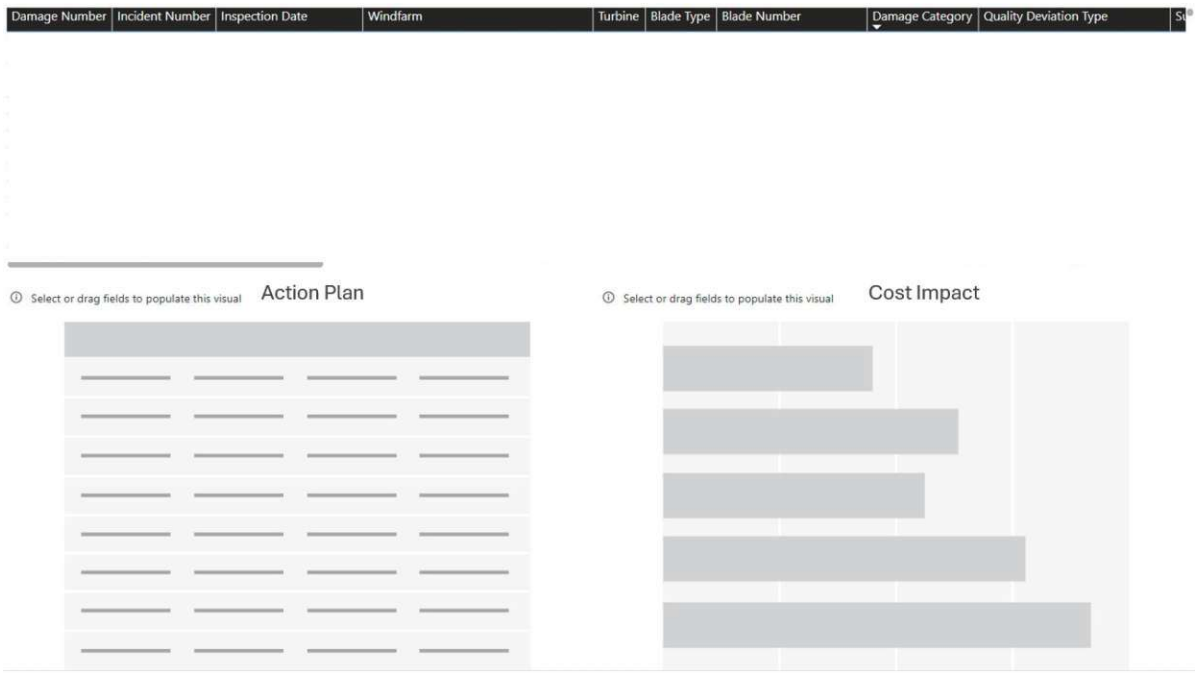

Figure 28: Interactive Reporting Template for Windpark Managers

Figure 28 shows the draft of an interactive reporting template that would be used to provide feedback to the windpark manager for evaluating costs and actions to be taken in their blades. This template would display the categories listed in section 3.5.2, while debriefing an action plan based on the technical requirements of the deviations, alongside their cost impact for better budgeting and communication of expenses. At the moment, the planning tool is still under development, hence no possibility to display its looks in the template.

The templates presented above would act as a reporting standard throughout the communication process in Figure 25. As mentioned, the process proposed should be repeatable and scalable, and these interactive tools bring the possibility to keep records of previous findings with clear visualization. Additionally, as said, Power BI offers the opportunity to have live data, and to filter it on several fields. Therefore, it would be possible to show all the data history for a specific windpark, turbine, or blade. This allowing to identify trends and have solid arguments to suggest and request actions from the departments in question.

Focusing on the communication process itself, another key point to consider would be to establish time frames for every action to be taken, in order to have an organized and well-timed flow of information that meets deadlines. To ensure that the agreed times are respected, the same Total Employee Involvement (TEI) strategy, from section 4.2, should be considered. Merging feedback-driven communication processes with TEI strategies solidify the workflow of the methodologies proposed by having a motivated and accountable workforce, that understands its impact and value within the process. The feedback communicated is then considered as a currency, meaning that the more information received, the more resources there are to investigate, evaluate, and

execute improvements with cohesive actions for a steady amelioration in the company's practices. Having a continuous exchange of information makes the involved staff feel responsible, triggering data communication as a standard rather than an occasional action. Therefore, by creating an environment that fosters respectful, responsible and constant feedback, methodologies and process can be successfully implemented when supported with the right tools, as it would be the case of communication workflows and reporting templates.

The following points summarize the findings from this section, bringing up coherent and valid ideas that interconnect with the previous results to generate valuable conclusions at the end of the study.

- The communication process suggested (Figure 25) acts as an improvement for the current process for post-installation findings, ensuring a broader reach to the data that is collected and analyzed. This process takes into account the relevant departments explored previously, which should enforce a continuous exchange of information with clear yet well-supported feedback for spotting areas of opportunity at different stages. Additionally, this process owns a high-level of repeatability and scalability, meaning that it can be replicated throughout the organization and that its implementation serves as a base for building-on-top improvement.

- The reporting templates produced act as supporting tools for the communication process developed. Having separate layouts for every reporting stage ensure the correct communication of relevant information for each stakeholder, facilitating feedback reception. Moving from 1 to 3 reports backs-up the process proposed without creating any additional workload due to the use of Power BI, which collects data automatically and enables efficient filtering of information. Additionally, these reports ensure the correct recording of data to support continuous improvement plans that could be undertaken at any level of the company structure.

- Identifying and taking into account factors that may support or hinge the correct functioning of the process should be an utmost priority. Establishing time frames for actionability is required to guarantee that feedback and relevant information will be received promptly when needed. To ensure that, a robust Total Employee Involvement (TEI) environment should be promoted, leading up to constant streams of communication with accountable and responsible handling of data. Therefore, accountability-focused practices should be undertaken by all stakeholders involved, where feedback becomes a habit rather than an occasional behavior.

The study realized in this section signifies an improvement to the current communication process for post-installation findings in the Service department, backed-up with a multi-departmental reporting structure and cohesive templates for efficient data communication and feedback leverage. The suggestions made are significant because of their connection wit the previous objectives, acting as a response to the need of stronger processes for cost awareness, claim management, multi-departmental communication and feedback utilization. Having assigned responsibilities within a data handling process

provides a clear understanding of the goals of the organization, alongside roles and responsibilities that every stakeholder should be accountable for. Similarly, this study is accurate and valid to due to the reasons aforementioned, as well as for the correct incorporation of current resources into the improvements made. The consideration of maintaining the same amount of workload but with better outcomes reflect on the accuracy of the method, meaning that the areas of opportunity were identified properly on the current organizational practices. Reflecting on repeatability and scalability also provide certain validation on the viability of the suggestions, since the align with the company's interests on having efficient methodologies with correct tooling for their execution, that also serve as a base for continuous improvement. Due to its repeatability, a closed-feedback loop could be the result of constant development of the process, yet it would a long-term outcome as a consequence of this first step. Nonetheless, the processes suggested bring other areas of opportunity to establish solid organizational practices for the upcoming market growth. Due to the expected growth, the following study will propose decision-making tools that display costs as a driver to evaluate the best possible outcome of the situation in doubt.

4.4 Tools for Costs Evaluation as a Support on Decision-Making

As it has been mentioned throughout the study, having tools to support processes is highly-important for their correct functioning and production of relevant outcomes. Considering the economical implications that quality deviations have for the company, developing tools for cost evaluation based on past data can significantly enhance decision-making processes. To identify and choose the appropriate approach, several factors should be considered. Hence, key considerations for this process are listed below.

- **Data Quality and Relevance:** Ensure the collected data is accurate, complete and up-to-date. The data must be filtered and categorized by relevance to the selected criteria.
- **Trend Identification and Forecasting:** Look for patterns in production costs, operational expenses, and overheads. This would support on distinguishing short-term fluctuations and long-term trends.
- **Market Growth Dynamics:** Factor in steady market growth rates by analyzing historical performance, as well as internal and external indicators. Taking into account the projected growth and possible variations is required for long-term forecasts and decision-making.

The first key consideration is addressed by the previous objectives of the study, which ensure an accurate flow of information, based on the requirements of the stakeholders involved. Trend identification and forecasting is a result of deep analysis triggered by feedback leverage and quality deviations processing. Market and growth dynamics need to be factored in for understanding the volume of incoming products to the Service department, which would then reflect an increase on data and operational practices. To create representative and significant cost evaluation tools, there must be an agreed

data integration and preparation process which ensures consistent and well-categorized data based on the requirements of the study itself. Also, key metrics and indicators must be decided to ultimately create a weighted criteria for each factor, evaluating their impact based on the interests of the study. Lastly, the process must be scalable and permit dynamic use of data that provides insights based on the newest data updates. Therefore, a Decision Support System (DSS) must be developed to provide actionable insights to decision-makers, allowing users to simulate different scenarios to understand their impact on costs.

Particularly for quality deviations, it would be important to understand the volume that they represent out of the total amount of findings. Similarly, there should be inputs on how many windparks are affected, including the amount of turbines and blades. Then, as it was worked in section 4.1, there should be the economical and operational downtime impacts considered in the calculations. Each of the factors mentioned should have a weighted criteria that assess their impact based on the requirements and interest of the users and stakeholders. As a results, an overall grade or ranking should be generated to represent its relevance and actions to take. Based on these points, the following cost evaluation methods for a particular quality deviation were developed, one representing an increasing trend and the other a decreasing one.

Quality Deviation Selected

Past Data	2023	10000	blade-related findings	60	windparks	900	installed turbines	€	15.000.000	blade-related labour costs	€	6.500.000	blade-related operational downtime costs
							Weighted criteria	Result		Total % of relevance based on criteria:			
	Amount of Findings	800	8,0% of total findings				25,0%	1,0%		**22,8%**			
	No. of WFs Affected	9	15,0% of total windparks				5,0%	0,4%					
	No. of Turbines	105	11,7% of total installed turbines				5,0%	0,3%					
	No. of Blades	86	3,2% of total installed blades				15,0%	0,2%					
	Labour Costs €	7.000.000	47% of total labour costs				20,0%	9,3%					
	(Repairs)												
	Op. Downtime Costs €	2.500.000	38% of total operational downtime costs				30,0%	11,5%					
	(LDs)												

	%	Priority	Action
	0 to 10	Low	No need
	10 to 20	Low	Continuous Tracking
	20 to 40	Medium	Make an internal action plan and communicate.
	50 +	High	Escalate for support and act accordingly.

Current Data	2024	12000	blade-related findings	63	windparks	968	installed turbines	€	16.000.000	blade-related labour costs	€	9.650.000	blade-related operational downtime costs
							Weighted criteria	Result		Total % of relevance based on criteria:			
	Amount of Findings	950	7,9% of total findings				25,0%	1,0%		**23,9%**			
	No. of WFs Affected	11	17,5% of total windparks				5,0%	0,4%					
	No. of Turbines	135	13,9% of total installed turbines				5,0%	0,3%					
	No. of Blades	101	3,5% of total installed blades				15,0%	0,3%					
	Labour Costs €	8.500.000	53% of total labour costs				20,0%	10,6%					
	(Repairs)												
	Op. Downtime Costs €	3.600.000	37% of total operational downtime costs				30,0%	11,2%					
	(LDs)												

	%	Priority	Action
	0 to 10	Low	No need
	10 to 20	Low	Continuous Tracking
	20 to 40	Medium	Make an internal action plan and communicate.
	50 +	High	Escalate for support and act accordingly.

Growth Factors		20%		5%		10%			10%			15%	
Forecast	2025	14400	blade-related findings	67	windparks	1065	installed turbines	€	17.600.000	blade-related labour costs	€	11.097.500	blade-related operational downtime costs
							Weighted criteria	Result		Total % of relevance based on criteria:			
119%	**Amount of Findings**	1128	7,8% of total findings				25,0%	1,0%		**27,9%**			
122%	No. of WFs Affected	13	20,1% of total windparks				5,0%	0,5%					
129%	No. of Turbines	174	16,3% of total installed turbines				5,0%	0,4%					
117%	No. of Blades	119	3,7% of total installed blades				15,0%	0,3%					
121%	**Labour Costs** €	10.321.429	59% of total labour costs				20,0%	11,7%					
	(Repairs)												
144%	**Op. Downtime Costs** €	5.184.000	47% of total operational downtime costs				30,0%	14,0%					
	(LDs)												

	%	Priority	Action
	0 to 10	Low	No need
	10 to 20	Low	Continuous Tracking
	20 to 40	Medium	Make an internal action plan and communicate.
	50 +	High	Escalate for support and act accordingly.

Figure 29: Representative Cost Evaluation for a Quality Deviation (Increasing)

Quality Deviation Selected

Past Data

	2023	10000	blade-related findings	60	windparks	900	Installed turbines	€	15.000.000	blade-related labour costs	€	6.500.000	blade-related operational downtime costs
Amount of Findings	800		8,0% of total findings				Weighted criteria		Result				
No. of WFs Affected	9		15,0% of total windparks				25,0%		1,0%				
No. of Turbines	105		11,7% of total installed turbines				5,0%		0,4%				
No. of Blades	86		3,2% of total installed blades				15,0%		0,2%				
Labour Costs (Repairs)	€ 7.000.000		47% of total labour costs				20,0%		9,3%				
Op. Downtime Costs (LDs)	€ 2.500.000		38% of total operational downtime costs				30,0%		11,5%				

Total % of relevance based on criteria:
22,8%

%	Priority	Action
0 to 10	Low	No need
10 to 20	Low	Continuous Tracking
20 to 40	Medium	Make an internal action plan and communicate.
50 +	High	Escalate for support and act accordingly.

Current Data

	2024	12000	blade-related findings	63	windparks	968	Installed turbines	€	16.000.000	blade-related labour costs	€	9.650.000	blade-related operational downtime costs
Amount of Findings	650		5,4% of total findings				Weighted criteria		Result				
No. of WFs Affected	8		12,7% of total windparks				25,0%		0,7%				
No. of Turbines	99		10,2% of total installed turbines				5,0%		0,3%				
No. of Blades	79		2,7% of total installed blades				5,0%		0,3%				
Labour Costs (Repairs)	€ 8.000.000		38% of total labour costs				15,0%		0,2%				
Op. Downtime Costs (LDs)	€ 1.900.000		20% of total operational downtime costs				20,0%		7,5%				
							30,0%		5,9%				

Total % of relevance based on criteria:
14,9%

%	Priority	Action
0 to 10	Low	No need
10 to 20	Low	Continuous Tracking
20 to 40	Medium	Make an internal action plan and communicate.
50 +	High	Escalate for support and act accordingly.

Growth Factors

		20%		5%		10%			10%			15%	
Forecast	2025	14400	blade-related findings	67	windparks	1065	Installed turbines	€	17.600.000	blade-related labour costs	€	11.097.500	blade-related operational downtime costs
81%	**Amount of Findings**	528	3,7% of total findings				Weighted criteria		Result				
89%	No. of WFs Affected	7	10,6% of total windparks				25,0%		0,5%				
94%	No. of Turbines	93	8,8% of total installed turbines				5,0%		0,3%				
92%	No. of Blades	73	2,3% of total installed blades				5,0%		0,2%				
86%	**Labour Costs** (Repairs)	€ 5.142.857	29% of total labour costs				15,0%		0,2%				
							20,0%		5,8%				
76%	**Op. Downtime Costs** (LDs)	€ 1.444.000	13% of total operational downtime costs				30,0%		3,9%				

Total % of relevance based on criteria:
10,9%

%	Priority	Action
0 to 10	Low	No need
10 to 20	Low	Continuous Tracking
20 to 40	Medium	Make an internal action plan and communicate.
50 +	High	Escalate for support and act accordingly.

Figure 30: Representative Cost Evaluation for a Quality Deviation (Decreasing)

The cost evaluation method presented in Figures 29 and 30 aims to display the percentage of relevance a quality deviation have, based on past data, current data, and forecast data. Additionally, for the forecast, growth factors are integrated that consider steady grow in windparks and turbines, hence increasing costs and findings. However, a trend in findings and costs is taken from historical and current data to factor that change into the forecast. As expected, there are more detailed and accurate ways of factoring in all relevant indicators, however this process could serve as a base to improve and adapt to the stakeholders' needs. Additionally, this method prioritizes actions based on the percentage of relevance, which should facilitate its incorporation in decision-making. Establishing the reactions that this study should trigger supports its scalability and repeatability since it allows to change the weighted criteria, based on the needs and interests of the users, but still displaying a standard value to assess the relevance of analyzing that quality deviation. Also, this could be utilized for broader cost evaluations (e.g. root causes) than particular quality deviations, bringing the possibility to evaluate long-term investments based on already collected and analyzed data, which considers growth factors alongside known implications that the studied area has within the organization. The benefits of integrating such tools for cost evaluation could be summarized in the following points:

- **Informed decision-making:** Decision makers can rely on data-driven insights to forecast costs accurately, leading to better resource allocation based on the indicators and criteria utilized.
- **Cost optimization:** By identifying trend and possible inefficiencies, organizations can reduce unnecessary expenditures and efforts on not-so-relevant topics, and focus their resources on areas that would have greater impact for the organization's profitability.
- **Scenario Analysis:** Evaluate the potential impact of various situations or changes on costs, enabling a more resilient methodology for resource allocation. This acting as a feedback and support on long-term planning and forecasting.
- **Proactive Positioning:** Understanding trends in costs allows for proactive adjustments to product placement strategies, providing deeper insights on maintaining healthy margins in the current and future operations of the organization.

The tool for cost evaluation introduced supports decision-making based on data collected, identified trends, and relevant criteria for the stakeholders. Still, there are other tools that can be developed utilizing distinct approaches. As explained in section 2.5.5, there are various forecasting costs techniques, but one that could be implemented based on the company's knowledge and resources is bottom-up estimation. Creating a bottom-up forecasting tool would involve structuring the collected data, identifying key variables, and developing a model that aggregates forecast from the granular (bottom) level to the overall (top) level. Similar to the other method proposed, this approach utilizes historical data, market indicators, product information, operational factors and assumptions

as inputs, to ultimately generate a granular cost forecast (e.g. deviation-level, product-level, region-specific costs) which would support the entire organization on visualizing trend, key drivers and variances for a well supported decision-making. The development of such process is out of the scope of reach of this study due to the level-specific data required, however it demonstrates the various possibilities that exist to utilize costs as a foundation for critical decision-making.

The correct implementation of cost evaluation methods in decision-making is highly significant for a smart and effective resource utilization. This study's significance lays on utilizing collected data as a source of information to assess and evaluate the impact of specific quality deviations for identifying the ones with the higher relevance factor. Due to the dynamic use of data and trends, this study becomes relevant for allocating resources to address impactful deviations promptly as an investment rather than an expense. Having a cost evaluation system with weighted criteria and a standard percentage of relevance, allows a fair comparison on priority levels for action, where all the needs and interests of the stakeholders are factored in. This proves the validity and accuracy of the study, since identified areas of opportunity are being addressed with repeatable and scalable methods that provide deep insights for a better decision-making. Due to the reasons mentioned, this study is could be considered as feasible, given that it has proved that with the current company's resources, relevant metrics can be developed. Overall, the cost evaluation methodologies proposed enhance an aware and well-supported decision-making process that could bring short and long-term benefits in a multi-departmental level. The following sections will conclude the project, presenting a holistic view of the results to answer the project's primary objectives.

5.0 Conclusions

This thesis set out to investigate methodologies to strengthen existing processes of communication, considering costs and blade quality deviations as drivers to foster a continuous improvement environment within the organization. This study aimed to understand the economical and operational impact of blade quality deviations, to suggest methodologies for deviations' identification and tracking with transparent communication channels, to ultimately expand on the tools and strategies that would act as a support to those processes. The findings revealed that quality deviations in blades after a year of installation signify elevated costs for the Service department, which should be communicated to the other blade-handling departments. Additionally, it was found that by analyzing root causes, it is possible to claim back up to 80 percent of the incurred costs to ease the profit and loss statements from Service. Due to the need of stronger communication process with extended reach, the study showed that methodologies can be followed to identify, evaluate and track blade quality deviations in a multi-departmental level. However, additional efforts need to be taken to promote a safe and accountable work environment where employees act as key sources of data input, motivating them to be accountable for the correct functioning of the company's practices. Similarly, it was found that a new platform with dynamic templates for reporting should be instated for multidisciplinary feedback, that is valuable and applicable to other standard processes already in place, maximizing the output by 3 times with the same resources. Ultimately, cost evaluation methods to support the decision-making throughout the several processes proposed were suggested, factoring in historical data, current findings, and forecasts that account for trends and market growth, which permit a clearer and potentially more efficient use of resources.

This research contributes with repeatable and scalable processes that foster a feedback-driven continuous improvement environment, where stakeholders are aware of the holistic relationship between quality deviations, incurred costs, and future impacts. Similarly, due to the steady growth of the company, this study provides communication methodologies that utilize company's resources for improved reporting that would support decision-making for addressing distinct challenges that are present and may arise from growth itself. The correct consideration of the current resources result on valid and viable suggestions for efficient practices that do not hinge the organizational values, but rather support them by improving the outcomes generated with similar implemented strategies and methods. While the study focused on identifying and improving communication process that leverage feedback for continuous improvement, it is from a Service department perspective which remains as a limitation given that blades are a multi-departmental responsibility and expanded alignment plans need to be explored for the correct implementation of the suggestions made.

Future research could investigate about cost management for significant evaluations and forecasts that accurately factor in criteria based on exact needs and interests, which could act as the company's primary decision-making tool. Additionally, research on extended quality responsibility could be relevant for supporting the communication methodologies proposed. Lastly, as mentioned previously, there must be a study on which are

the most beneficial communication channels and platforms that suit multi-departmental collaboration, enhancing a centralized data collection system that produces relevant outcomes in a multidisciplinary level. Nonetheless, this project has covered feedback management in a detailed manner, which serve as a base to bring continuous innovations that meet the company's needs and interests. By understanding and managing data accurately, diverse outcomes can be produced to take better decisions, and most particularly, to identify which are the areas where quality is compromised, being cost-aware and working on action plans that bring continuous improvement in a technical, operational and human level for the organization. At last, it is important to understand that costs are key drivers in the decision-making, therefore by utilizing data to back up decisions should be an utmost priority to every organization, while ensuring that their stakeholders are accountable, responsible, and aligned with the company's goals and vision.

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