LINKÖPING UNIVERSITY | DEPARTMENT OF MANAGEMENT AND ENGINEERING

MASTER'S THESIS, 30 CREDITS| QUALITY MANAGEMENT

SPRING 2024| ISRN: LIU-IEI-TEK-A--24/04925--SE

Enhancing Data Visualisation for Nuclear Power Plants

– A Quality-Based Approach for Vattenfall's Forsmark Facility

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ABSTRACT

With the growing reliance on data driven decision making in quality projects, the importance of data visualisation directly influences the project outcomes. This thesis will investigate the potential of quality management tools and principles during development of a visualisation tool. This tool was developed for Vattenfall AB to increase understandability and access to temperature and radiation data.

The research methodology included integrating with the visualisation team at Forsmark to observe, discuss, and interview key stakeholders. The information gathered were structured using the Kano model and translated through the Quality Function Deployment (QFD) house of quality, leading to the development of a visualisation tool utilising Power BI, principles of effective visualisation and Statistical Process Control (SPC).

The findings demonstrate that quality tools can be successfully adapted to new and specific contexts and successfully develop a powerful visualisation tool. The application of effective visualisation theories and SPC significantly enhanced data understandability and could potentially reduce analysis time for Vattenfall in the future. But some limitations were noticed, such as overlapping end user needs within the Kano model categories or subjectivity within QFD. The study concludes that while quality tools are broadly applicable in different settings and industries, they need ongoing refinement and adaptation to their frameworks to be truly universal. This thesis highlights the need of continuous improvement in quality tool methodologies to meet evolving industry needs.

Key words: Quality management, Visualisation, Nuclear power plant, Kano model, Quality Function Deployment (QFD), Effective visualisation, Statistical Process Control (SPC).

Preface and Acknowledgement

This paper presents my master thesis researching quality management in a nuclear power plant visualisation process at Vattenfall AB. The thesis marks the end of five long years to become a Master of Science in mechanical engineering at Linköping's University and shows my accumulated experience in quality management.

I would like to express my gratitude to my thesis supervisor Mattias whose expertise, understanding, and guidance, added considerably to the success of this thesis. I appreciate all the inspiring advice and your positive mindset during the thesis's many challenges.

I would also like to thank my supervisor from Vattenfall Forsmark, who was abundantly helpful and offered assistance and support throughout the project. I would also want to thank all the employees at Vattenfall Forsmark who I had the pleasure to work with. Your insights in the interviews were very important for the successful results, and the welcoming atmosphere during my visits made this thesis an unforgettable experience.

Finally, I would like to express my appreciation to Roseline and Elin for their valuable feedback and insights, which greatly enhanced the quality of my work.

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1 INTRODUCTION

This chapter presents the context of the research area with a description of the problem and the research questions studied. Additionally, related work of similar research areas is presented followed by the scope, outline and ethical consideration of the thesis.

In today's digital age, and digitally based quality management, data visualisation and data analysis have become more and more important. To be able to communicate data effectively is to be able to make data driven decisions and to find interesting information within the data such as trends, patterns and outliers (Unwin, 2020). This visualisation of data is the base to insights within any process and can contribute to innovative solutions, solving business challenges or increasing efficiency in operations (Unwin, 2020), which is the foundation of what is called continuous improvements.

Quality management is a way to increase and keep products and services at a high quality standard set by the customers or end users (Gremyr, et al., 2020). By using different principles, methods and tools, quality management can increase customer satisfaction, increase efficiency and reduce wasteful activities or production. By having quality standards and using quality management in an organisation, end products or services will be of higher quality and with the potential to surpass customers expectations (Gremyr, et al., 2020). One of the main aspects and principles of quality management is continuous improvement, or "Kaizen", which is a mindset and strategy where processes and products endlessly improve over time, and to continue to search for new improvement areas (Imai, 1986).

The improvement of a visualisation process is a continuous improvement initiative that integrates quality management principles in a digital setting. Visualisation tools increase the accessibility and usage of data to users which can increase efficiency in any data driven process. Digital tool can also reduce the human error of data visualisation by automatically generate visuals and graphs from updated data while at the same time give further feedback on improvements, continuing the continuous improvement cycle.

This thesis explores the possibilities of quality management in visualisation process improvements.

1.1 BACKGROUND

Vattenfall AB, founded in 1909, is one of Europe's largest energy companies with a commitment to sustainability and green energy solutions (Vattenfall AB, 2024). Their history is filled with their adaption to the changing landscape that is energy generation. From their beginnings in hydroelectric power to a much broader focus with wind power, solar power and nuclear power. Their mission, according to Vattenfall AB (2024) is to reduce carbon emission and to create a green energy system by increasing their focus on renewable energy. A notable aspect of Vattenfall's contribution to the energy sector is its management of the Forsmark Nuclear Power Plant, a facility on Sweden's east coast that has been a key electricity provider since the 1980s. With its three reactors Forsmark creates 25 TWh/year, which is approximately 15% of Sweden's total energy production, making it Sweden's largest energy producer (Vattenfall AB, 2024). Nuclear power plants come with many challenges, one of those is the prediction and analysation of temperature change and radiation dosage in the environment surrounding the core. This environment's function is to sustain the core’s functionality and to ensure operational efficiency in generating power while absorbing some of the excess heat and radiation generated. With constant temperature changes and constant radiation, components in these environments needs to fulfil many specifications to ensure operational safety.

It is relatively easy to re-buy components that have already been confirmed to uphold the required specifications, but what if a new component needs to be added? What temperature changes, radiation and effects does that component need to sustain to be classified for a nuclear power plant? This is one of many challenges at a nuclear power plant, and to address this, Vattenfall employs a process of gathering these environmental factors. The data is currently used to determine the state of durability for current components, however, the current system reveals many limitations which impacts efficiency in its usage and the accessibility of the data. The current process to gain these insights, and to communicate them, does not have a standardised method but often consists of creating new measurements or going through old PDF files re-collecting data every time an analysis needs to be made. These inefficient methods highlight the need for innovative solutions to improve the visualisation method at Vattenfall.

1.2 PURPOSE AND RESEARCH QUESTIONS

The purpose of this thesis is to use quality methods to develop a visualisation tool that will enhance communication of data between various stakeholders. The tool is intended to increase data access across various parts of the organisation, ensuring that the information is not only more readily available but also intuitively understandable to individuals regardless of their prior knowledge. The tool will also increase access to historical data at different locations in the power plant to enhance classification of new components.

To ensure that the tool is effective, these research questions need to be answered:

- How can quality tools effectively identify and address the needs of end users in the development of a visualisation tool in a nuclear power plant?
- How can a quality-based visualisation tool improve the visualisation process and increase the understandability of the current data in a nuclear power plant?

1.3 RELATED WORK

By examining the contributions and limitations of prior works, the thesis aims to position its research within the broader academic context to ensure that the approach both aligns and diverges from established practises.

Colour stratification in visualisation

Wu and Xu (2020) investigate the design of information displays in nuclear power plants control rooms, with a particular focus on optimising operator monitoring behaviours and enhancing cognitive performance. Their research concentrates on the visualisation of boron and water supply systems, proposing a visual design model that merges user tasks and perceptions to determine relevant information presentation and colour-coding schemes. Wu and Xu (2020) conclude their research with a new visual model for nuclear power plants where they prove efficiency increase from colour stratification of data. By using different colours for different information, users could use the interface faster and could understand its properties with greater ease, which boosts the overall efficiency of the work. However, they note a limitation in their research scope, as it does not explore variations in layout or visual elements beyond colour coding which leaves many areas to be explored (Wu & Xu, 2020).

Interactive visualisation

Zhang et al. (2021) address the critical issue of radiation visualisation through an interactive system designed to support safety and construction planning amid the increasing reliance on nuclear energy. Their system employs human perceptual principles to map radiation levels effectively, using colour and density cues to increase understanding. The interactivity ensured that users could engage deeper into the data and gain a better understanding of what the visuals communicated. But despite its advancements, the study acknowledges the need for further improvements based on feedback from experts, highlighting ongoing challenges in accurately representing data and challenges in gathering system requirements (Zhang, et al., 2021).

Human factors in visualisation

Human factors play a large role in the design and usage of digital control systems for nuclear power plants, aiming to enhance safety, efficiency, and usability in plant operations. This area is investigated by Ulrich et al (2012) during a modernisation process, where the control room increased its digitalisation, to create a set of recommendations based on human factors. Ulrich et al (2012) emphasises the importance of analytical evaluation and expert reviews by subject matter experts to identify potential improvements to the displays. They also highlight the selection of appropriate usability guidelines, such as Nielsen's usability heuristics, Gerhardt-Powal's cognitive engineering principles, ISO standards, and ISA standards, to ensure good usability for an interface. The findings Ulrich et al (2012) present are a set of nine recommendations, such as colour, control charts and navigation, for future design of digital systems in power plants that emphasise human factors (Ulrich, et al., 2012).

1.4 LIMITATIONS AND SCOPE

As the thesis have a limited timeline some limitations have been set.

- The thesis will only investigate the nuclear power plant of Forsmark, and the tool will be developed after specifications related to their specific challenges.
- The visualisation tool's potential to be generalised across multiple power plants will not be investigated.
- The end result will only consist of the tool and its creation/development and there will be no intensive studies or pilot studies for its actual efficiency effect. The result will only be validated through qualitive interviews with the stakeholders who will give their input and thoughts on how it will potentially affect their future work.

1.5 OUTLINE OF THE THESIS

With the background known, the thesis continues in chapter two with a case study methodology explained and how different methods contributed to data collection and data analysis. It also presents the literature review and interviewing techniques. Afterwards, the theory in chapter three used in the thesis is explained and their adaptations and potential drawbacks to the thesis research area are presented. Afterwards in chapter 4, the first set of results are presented, including the program selection and end user specifications. Chapter 5 includes the second set of results presenting the visualisation tool development process. The thesis ends with a discussion of how the theories correlate with the results and the research questions are answered with recommendations for future research areas.

1.6 PROJECT ETHICS AND SAFETY CONSIDERATIONS

The development of a visualisation tool for nuclear power plant operations sits at the intersection of technological innovation and ethical responsibility. This chapter aims to address the ethical considerations inherent in creating a tool that has the potential to influence the safety, efficiency, and transparency of nuclear power generation. But also, the risks and ethical responsibilities of writing a master thesis, especially when involving sensitive power plant information.

1.6.1 Safety and reliability

Safety and reliability are split into two main areas that are most important to the thesis, the development of the tool and thesis report.

Tool development

The most important ethical consideration in developing a nuclear power plant visualisation tool is its impact on safety and reliability. Given the catastrophic consequences of failures in nuclear power plants (World Nuclear Association, n.d), it is ethical to ensure that the tool enhances, rather than compromises, the safety of plant operations. Misinterpretations, simplifications, or misrepresentations of important data can have severe effects on safety which makes accuracy extremely important. During development, all data processing will use transparent documentation and be audited internally by stakeholders to ensure an effective understanding of the tool.

Thesis report

Nuclear power plants are some of the most protected industries where information is vital to the security of the country it resides in (Strålsäkerhetsmyndigheten , 2023). The nuclear power plant Forsmark is considered a high priority target for foreign intelligence agencies and an attack target during war times which makes all aspects of safety crucial (Strålsäkerhetsmyndigheten , 2023). Therefore, the information displayed and discussed during the thesis will have to be checked and confirmed by Vattenfall's security team before any third-party is allowed to read it. The results from the thesis will thus be altered to ensure that no sensitive information is published, and aliases will be used for all Vattenfall associates to protect their privacy and prevent attention to their positions.

1.6.2 Plagiarism

Plagiarism directly undermines the foundation of academic integrity, which is built on honesty, trust, and responsibility. Academic institutions rely on these principles to ensure that the work produced contributes genuinely to the field of study, reflects the author's own understanding and analysis, and can be trusted by others as a reliable source of knowledge. Proper citation and avoidance of plagiarism are also matters of fairness and respect for the intellectual contributions of others (Helgesson & Eriksson, 2015). By acknowledging the work of previous researchers and by providing correct credit, this thesis will support ongoing research. The author will also ensure correct representation of others figures and result as not to contribute any misunderstandings. In some cases, plagiarism can have legal ramifications, especially when copyrighted material is used without permission (Helgesson & Eriksson, 2015).

The increasing popularity of generative AI, such as ChatGPT, presents new challenges and opportunities in academic writing. While these tools can assist in discussing ideas, providing information, and even helping with the structure of academic texts, their use must be carefully managed. Therefore, generative AI will not be used as a source of information, AI will only influence this thesis as a brainstorming tool by the author and to give bullet point reviews on the thesis structure.

2 METHOD

This chapter explains the methodologies used and the overall structural approach of the thesis. It also presents the literature review, interview structure and data collected.

This thesis adopts a three-phase case study methodology to tackle the challenges and to structurally form a solution in the context of nuclear power plants and their visualisation systems. This methodological choice is grounded in its proven efficacy for generating nuanced insights into a real-life context and is recommended by the educational researcher Thomas (2011). The approach starts with a literature review and is followed by a "Data Collection" and "Data Analysis" phase to ensure a structured and accurate exploration of the subject matter, see Figure 1.

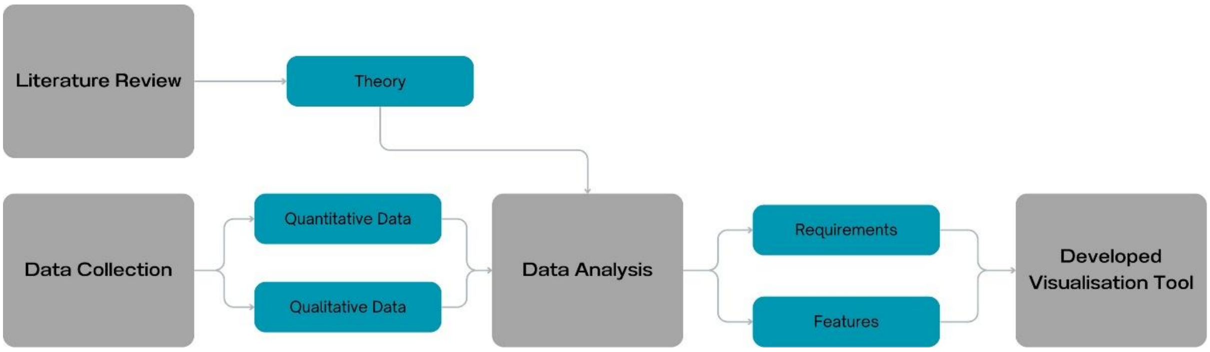


Figure 1:The case study structure and connections.

2.1 CASE STUDY

Developing a visualisation tool adapted to a nuclear power plant is a niche yet critical area of research. Case studies are adapted for such specialisation as this method shines in addressing practical challenges, offering solutions and insights with direct real-world applicability (Thomas, 2011). Moreover, it lays the groundwork for identifying future research avenues, thus advancing the field of visualisation within nuclear facilities. The practical aspects of a case study also means that the study is relatively narrow in its research scope which can hinder any generalisation of the findings and limit future work in other areas (Thomas, 2011; Tellis, 1997). Case studies use different sources of data such as interviews, quantitative data and/or document analysis to give a complete image of the problem and the findings. When merging sources of different kinds of data, and during collection of said data, there is high risk of subjective viewings that can influence the reliability of the research (Tellis, 1997).

2.2 LITERATURE REVIEW

This thesis relies on multiple known methodologies and theoretical approaches as the foundation for the development of the visualisation tool. Therefore, the initial phase of the project consisted of a literature review of both related work and the theoretical framework. To gather the necessary information, articles recommended in multiple different courses at Linköping's University were used as a starting point. These articles have already been approved by established teachers, scholars, and professors to be trustworthy and a good basis for research. To continue the research with established articles, the citations, and references of said articles were explored.

To gain further insights into more specific areas, Google Scholar and Unisearch were used to gather articles. When searching for relevant information multiple keyword combinations were needed, these were: Visualisation AND Nuclear power plant, Quality tools AND Software development, Effective visualisation AND nuclear power plant. These combinations had hundreds of thousands of results which had to be filtered further, this was done with the help of the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) model. The PRISMA model sorts out found papers with the help of a set of criteria set by the author (Moher, et al., 2009). The criterion for this review consisted of relevancy to the background and purpose of this thesis such as articles that have purposes and research questions that are similar to this project. The first filter was to remove duplicates and only include articles the author had access to. Secondly only full text articles were used, which lowered the number of papers to 219. After screening the articles only nine additional papers were thoroughly analysed, with 15 papers coming from the university recommendations. This process is represented in Figure 2.

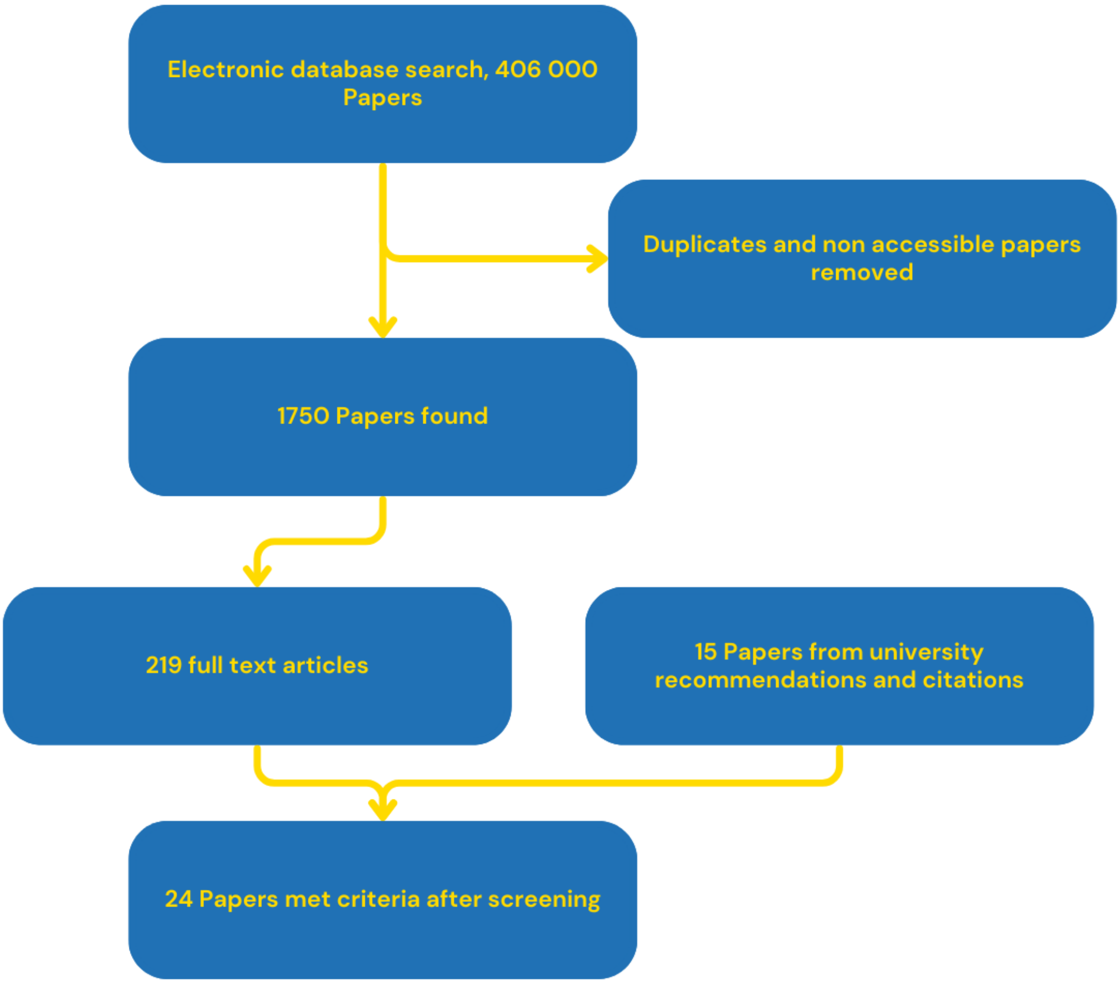


Figure 2: Literature review filtering process based on PRISMA.

Even though there are many papers on similar subjects, none of them were quite as specific or in the same area as the outline of this thesis. None of the papers discussed visualisation of temperature or radiation over time in the environment of the plant but more as design parameters. Similarly, quality tools are rarely used in power plants when developing visualisation tools which further provides authenticity to the originality of this project.

2.3 Stage 1 – Data collection

The first step of the case study was the data collection stage. This stage managed both the data that had previously existed and the data that was missing and needed to be gathered. During this stage, quantitative data were already gathered by Vattenfall by placing measurement nodes in the power plant, and qualitative data came from interviews and observations from the nuclear power plant operations.

2.3.1 Interviews and observations

During the thesis, the author had opportunities to visit and integrate with both the process and stakeholders at the nuclear power plant site. These visits gave insights through observations and created the possibility to further interview employees, see Table 1. Due to the setting in which the author could integrate with the process, the Unstructured and Semi-structured interviewing methods were used. To identify the subjects discussed during the interviews, the author used brainstorming with observational data as foundation.

Unstructured interviews are the method of collecting information through field observations and discussions that does not use a tangible goal (DiCicco-Bloom & Crabtree, 2006). By observing the process that is correlated to the thesis, one can gain information about habits, working methods, usage potentials and stakeholders who will be most affected or who holds the most relevant information. Through conversations and discussions, these stakeholders will function as informants who further increases the understanding of the process (DiCicco-Bloom & Crabtree, 2006). This means that unstructured interviews use multiple sources of data to gain a holistic view of the subject. The Unstructured interviews were dominant during this thesis and consisted of open-ended subjects and questions in short spurts. These discussions often took around 5-10 minutes, but every subject was interviewed multiple time so that the employees could have time to think of answers and the author could more easily adapt the questions.

Semi-structured interviews use a relaxed structure to align the interview questions towards a goal (DiCicco-Bloom & Crabtree, 2006). One of the most common structures used is a pre-booked one-on-one interview that touches upon predetermined general subjects. It is the interviewer's role to steer the conversation towards these subjects and to follow up with questions that can lead to informative answers. These interviews, when used in one-on-one settings, usually leads to individual perceptions of the subjects which means that it requires multiple interviews or a focus group to be able to gain a holistic view (DiCicco-Bloom & Crabtree, 2006). The semi-structured used were few but more in-depth of the different subjects.

Table 1: Interview overview

Title/person of interest	**Interview style**	**Subject discussed**
Manager of department	Semi-structured	Goal of project, Tool usage and potential
Senior Analysis employee one	Semi-structured & Unstructured	Tool usage and potential, Program selection, Goals of project.
Senior Analysis employee two	Unstructured	Tool usage and potential, Program selection.
Analysis employee one	Semi-structured & Unstructured	Tool usage and potential, Program selection.
Analysis employee two	Unstructured	Tool usage and potential, Program selection.
Analysis employee three	Unstructured	Tool usage and potential, Program Selection.

The subjects the author used as basis for the interviews:

Goal of project

These questions were directed to the department manager and to the supervisor to clarify the project's ultimate objectives and purpose. The discussions focused on the manager's and supervisor's expectations and the resources available to the author.

Tool usage and potential

Questions for the tool usage was connected to how the tool could fit the process it was supposed to be integrated with. This included discussing both the program's requirements, in which the tool would be developed in, and specific needs related to the program. The tool potential was instead directly related to the end user requirements. Questions about the tool's potential were aimed at understanding the end users' needs, including what features were necessary, beneficial, or undesirable. These interviews often involved comparing previous similar tools or projects.

Program selection

The program selection interviews discussed the potential programs that could be used and what factors that would be important in choosing a program. At the same time, a comparison of these programs was conducted with the employees.

2.3.2 Quantitative data collection

Before this thesis began, the quantitative data had already been collected over the years, meaning there was no need for extensive new data collection. However, the existing data had not been organised in a manner conducive to analysis which meant that a re-collection of data were needed. The available information was stored in PDF files, with each year represented by separate files for data and corresponding measurement details such as position, object, or measurement number, see Table 2. For analysis purposes, it was essential to combine these files into a single Excel spreadsheet, where all temperature and radiation measurements were linked with their corresponding positional and other measurement details.

Table 2 The quantitative data used.

Measurement information	**SI-unit/Data type:**
Year	[Date in Years]
Reactor	[Integer]
Data logger number	[Integer]
Height (Position)	[m]
Degree (Position)	[Degree °]
Object	[Plain text]
Measures	
Temperature Average	[°C]
Temperature Max	[°C]
Radiation dose	[Gy]
Radiation accuracy (+/-)	[Gy]

Additional information and categorisation:

- Total sample size was 314 for temperatures means and max and 140 samples for radiation doses.
- Reactor refers to which reactor that the measurement took place in. Forsmark Nuclear power plant has three reactors where two of the reactors were built after the same schematics and at the same time. This means that two reactors could have similarities while the third one, built with different techniques and with different layout, structure and components, could differ a lot.
- Due to the circular form of the measurement area, the degree data shows the position of the measurement node and is categorised into circular quadrants for some parts of the analysis.
- The height data, similar to the degree data, presents the measurement nodes height position, which for some parts are categorised as different floors.

2.4 STAGE 2 – DATA ANALYSIS

After conducting the first set of interviews for program selection, and transcribing responses, the first part of the analysis could be performed. To find out which program would be suited for the tool, a couple of well-known visualisation tools were compared to each other in different categories that derived from interviews, observations, and literature. With the help of interviews, the categories were weighted, and the different program choices could be compared. The comparison consisted of numbering each program in each of the categories depending on how well the program fulfilled the category. By summarising the resulting numbering, each program could gain a final score.

As the tools development would be adapted to end user needs, the next set of interviews would be for end user requirements and the results would have to be categorised and prioritised. To ensure precise categorisation and prioritisation a method of end user analysation was needed. This was done through the Five-level Kano model which is a model use to define end user needs (Witell & Löfgren, 2007). The Kano model, when compared to similar models, has higher accuracy, and was recommended by Witell and Löfgren (2007) to be used for situations where customer or end user views are crucial. This model was used to aid in the interviews, to ensure that the author gained information in the correct areas, and then used to categorise the results. These results were also prioritised by the kano model's categories. While the author conducted the categorisation of interview outcomes into Kano model categories, the primary categorisation stemmed from the interviews themselves.

The Kano analysis identified essential end user needs and their relative importance, but to translate them efficiently into tangible development steps a Quality Function Deployment (QFD) house of quality was used. The QFD house of quality aids in giving a structured approach to development processes by correlating user needs to product functions. The house of quality was used to brainstorm functions that would fulfil end user needs by using the tool as a checklist. When all the user needs were fulfilled by functions, and any related function synthesised, a correlation matrix in the house of quality were filled. This correlation matrix was used to find correlations between the functions themselves to find any limitations. The QFD house of quality could identify correlations early and ensure that the functionalities to be developed was going to meet end users needs and has proven success in development projects such as software development (Gustafsson, 1998).

The functions resulting from the QFD needed to be translated into an action plan for the tool development. This was done by creating a diagram that showcase the end users navigational and usage option of the end tool, based on the features from the QFD. More precisely, the functions were grouped together if they were relevant to each other, then they were given a category representing the page developed in the tool and connected together through a navigation system. This diagram served as a foundational element in development, outlining all components required to meet end user needs as a system.

With a diagram explaining the tools functionalities, the only thing left was the actual development. The tool was developed in accordance with the diagram, with some design changes made during the development. To effectively develop a visualisation tool, two methods were used and integrated. Statistical Process Control (SPC) control charts were used to ensure that the tool not only displays data but also provides insightful analysis. This approach uses statistical methods to generate alerts and offers analytical perspectives on potential anomalies and special causes (Montgomery, 2019). Furthermore, effective visualisation was also implemented, but as design choices and through colour stratification so that tool becomes simple to use (Tufte, 2007). The development was made page by page, first the functionality of each page was created to ensure that the tool would fulfil its basic functions. Then interactivity was added and integrated to enhance user engagement and understanding, ensuring that from the start, users could easily navigate and interact with the tool. Lastly the tools design was made with effective visualisation theory in mind. These three steps ensured that the tool would fulfil end user needs even if it would not be finished.

3 THEORETICAL BACKGROUND

The theoretical background represents and explains the theory behind the methodology, it also gives insights into adaptations that relate to the thesis. Common challenges that the theories bring is also presented in relevant sections.

3.1 FIVE-LEVEL KANO MODEL

The Kano Model was introduced by Professor Noriaki Kano, a Japanese professor and consultant, in the 1980s to help companies understand and prioritise customer needs in product development (Kano, et al., 1984). The model originated from Kano's observation that customer satisfaction does not always follow a linear relationship with product features (Kano, et al., 1984). He recognised that certain attributes had a different impact on customer satisfaction, and their importance could be categorised in distinctive ways (Kano, et al., 1984), see Figure 3.

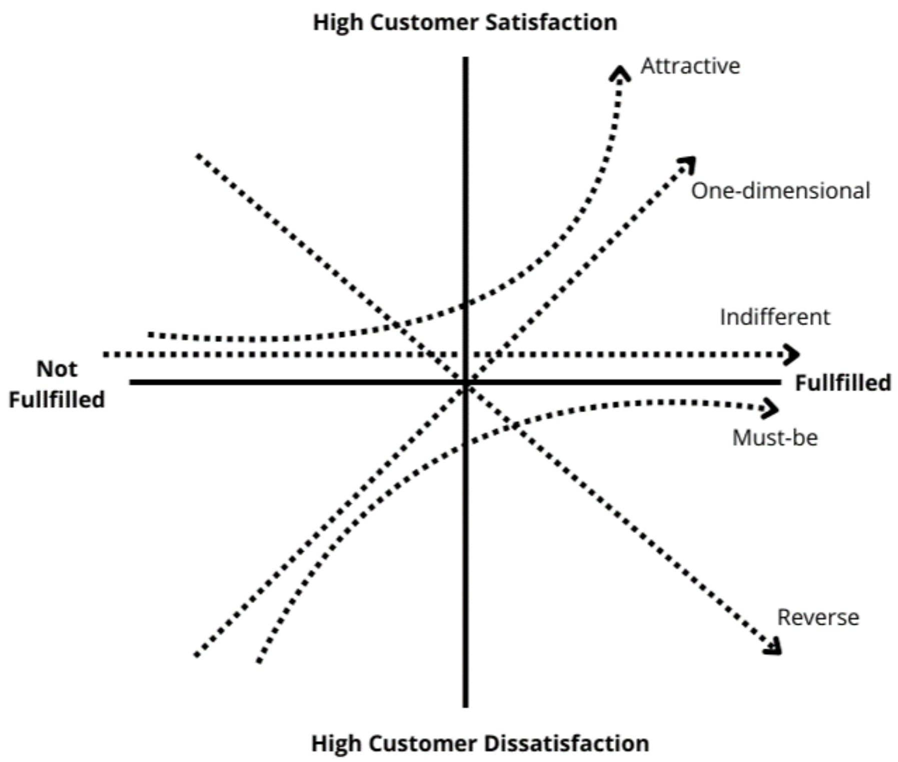


Figure 3: Presentation of the five-level of the Kano-model based on Löfgren & Witell (2008).

Must-be quality attributes are necessary attributes that are often overlooked by customers and stakeholders (Kano, et al., 1984). Customers and stakeholders usually do not communicate these needs because they are often considered basic and fundamental design properties of said product or service (Löfgren & Witell, 2008). If fulfilled, customers or stakeholders will often not take notice but if they are missing it will create major dissatisfaction (Kano, et al., 1984).

Attractive quality attributes are attributes that are not expected but positively received by the customer or stakeholder (Kano, et al., 1984). These attributes are seldom communicated effectively as customers and stakeholders do not expect them but instead see them as a surprise quality (Löfgren & Witell, 2008). As a result, these attributes create satisfaction when present but does not generate any dissatisfaction when missing (Kano, et al., 1984).

One-dimensional quality attributes are attributes that create satisfaction when present and create dissatisfaction when not (Kano, et al., 1984). These attributes are sometimes referred as "more is better" as more of the quality results in more satisfaction (Löfgren & Witell, 2008).

Indifferent quality attributes are attributes and features that does not affect the satisfaction nor the dissatisfaction of the customer or stakeholder (Löfgren & Witell, 2008).

Reverse quality attributes are similar to the one-dimensional but as the name suggests, reversed. These attributes or features result in dissatisfaction when fulfilled and satisfaction when not and should therefore be avoided (Löfgren & Witell, 2008).

The Kano model effectively understands what features and attributes are important and how they affect stakeholders (Witell & Löfgren, 2007). The model clarifies and communicates the needs that customers and stakeholders want in a priority order while also finds needs that might be unknown to the customers themselves. This information helps developments in their early stages by ensuring needs are accounted for (Löfgren & Witell, 2008). The model continues to add value to development by encouraging innovation and attractiveness (Witell & Löfgren, 2007) while mitigating risks of dissatisfaction (He, et al., 2021).

The model has also evolved in specific development areas such as software development. Kern and Refflinghaus (2018) explored this area by researching potential adaptations of the kano model to fit the development of an excel-based tool. During their research they confirmed the effectiveness of using the Kano model to gain insights into the requirements when developing software. Even though the model is a good fit the authors present a model to include individual and subjective requirements because software qualities can be different for different people. Their model is based on individual weighting of each requirement/attribute which are then given an individual curve on the Kano graph. Their model theorises that each result should also have an independent satisfaction result, meaning that a one-dimensional could be more satisfactory than an attractive quality due to customers' personal opinions. Their work gives an insight into the importance of weighing requirements appropriately and that in software development, qualities and satisfaction can differ depending on the individual (Kern & Refflinghaus, 2018).

Despite its advantages, the Kano model is not without challenges. The model struggles with being objective as the user is the final determinator of categories for the attributes investigated. Even though multiple stakeholders participate in the categorisation, there will always be some degree of subjective viewing influencing the result (Mikulic & Prebežac, 2011). The relations between the factors and satisfaction are also considered highly coincidental and are affected by multiple factors that can be challenging to predict (Slevitch, 2024). Furthermore, the categorisation is different depending on the market and culture because what we consider important here is not equivalent to what is important on the other side of the world (Latta, 2019). A similar argument can be said for the satisfactory change over time as it is common for attractive qualities to become must-be qualities, or even a reverse quality (Mikulic & Prebežac, 2011). What is considered new and innovative today will be redundant tomorrow, which is a factor that is seldom considered.

3.2 STATISTICAL PROCESS CONTROL

SPC has its roots in 1920s when Shewhart introduced his Shewhart charts, evolving from the collaboration between statisticians and quality control experts (MacCarthy & Wasusri, 2002). Pioneering figures such as W. Edwards Deming and Joseph M. Juran laid the groundwork for SPC within the framework of Total Quality Control (Deming, 1986; Juran, 1992). Their emphasis on continuous improvement and customer satisfaction provided the foundation for integrating statistical methods into quality management.

By applying SPC methods, anomalies and outliers can be detected and addressed to make sure that the data reflects the conditions of processes accurately (Montgomery, 2019). With statistical thresholds and control charts, SPC allows users to make data-driven decisions and can reduce the influence of personal bias which can help with the challenge of subjectivity (Pujar, et al., 2010). As new data is collected and analysed, SPC can also help identify trends and shifts in operational parameters, which enables the tool to adapt and improve over time (Lim, et al., 2015).

Because SPC uses complex statistical charts and tools, it can be difficult to understand if the users do not have any prior experience (MacCarthy & Wasusri, 2002). This complexity can lead to misunderstandings of the data or resistance to use it which could hinder its implementation. The effectiveness of SPC is also heavily dependent on the quality and availability of data (MacCarthy & Wasusri, 2002). Poor data quality, including inaccurate and missing data, can lead to misleading SPC analyses and conclusions. Another issue lies in SPC's principles of continuous improvement, which requires ongoing effort to maintain process controls and to seek out improvements (Jurburg, et al., 2017). This can lead to improvement fatigue among employees, especially if the benefits are not immediately visible or if the process of identifying and implementing improvements is viewed as demanding (Jurburg, et al., 2017).

The foundation of SPC involves multiple fundamental statistical concepts. Measures of mean, median and measures of range, standard deviation are crucial for interpreting process variation (Montgomery, 2019). There are two types of variation that are critical to SPC according to Montgomery (2019);

- Special Cause Variation: These are unusual events that are not part of the process' natural variation. Identifying and eliminating special causes can lead to significant improvements in process performance.
- Common Cause Variation: This is inherent in the process and occurs randomly. It represents the natural fluctuation in process output when the process is under control. Control charts help in understanding the extent of this natural variation.

3.2.1 Control Chart

Control charts, introduced by Shewhart in the 1920s, can effectively visualise process variation by plotting data over time (Montgomery, 2019). The underlying theory of control charts is grounded in statistical theory, particularly in the concepts of variation and distribution (Shewhart, 1931). Most processes will exhibit variation in their output, but the goal is not to eliminate all variation, which is impossible, but to manage and control it (Montgomery, 2019). The control chart uses control lines to determine if a process has special cause variation, these lines are representing standard deviation. Depending on the process, these control lines can be up to three times the standard deviation in both directions, which is the statistical limit (Montgomery, 2019), see Figure 4.

To see which variation one needs to improve upon, the data dots in the chart needs to be studied. There is a set of five rules and if any of these rules are broken then the process has special cause variation which needs to be addressed (Lloyd, 2019). But if none of the rules are broken then the process is in control and can only be further improved by addressing common cause variations. The special cause variation rules, according to Lloyd (2019) are as follows:

- One or more points above/below three standard deviations, presented in Figure 4
- Two out of three points in a row above/below two standard deviations.
- Eight or more points in a row on the same side of the centre line.
- Six points going up or down in a row, presented in Figure 4.
- 15 points or more in a row under one standard deviation.

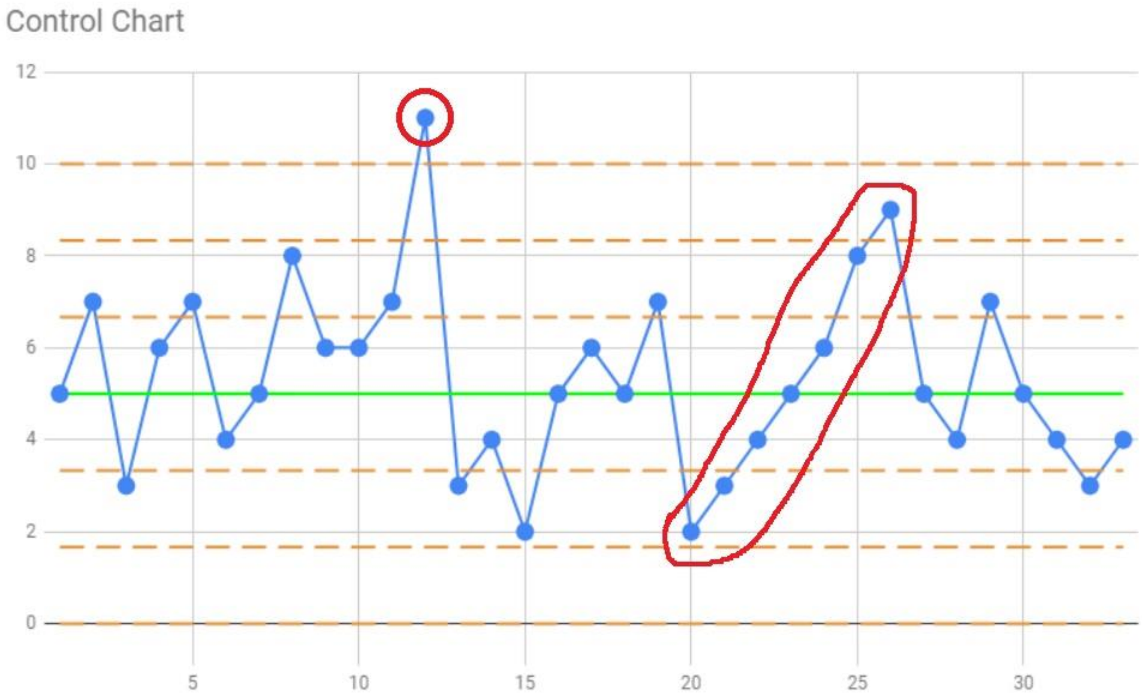


Figure 4: A control chart with green centre line and orange control lines representing one standard deviation each. There are also two special causes: one point above three standard deviation and a trend of seven points going up.

With these charts one can easily identify if it is a special cause or common cause variation one needs to improve upon (Shewhart, 1931). Furthermore, it can monitor process stability of data over time and create the basis for informed decisions regarding process control (Montgomery, 2019).

Kindler and Martinson (2024) investigate the application of SPC and control charts within a visualisation tool dashboard designed for clinical care. Their study demonstrates that SPC and control charts are highly effective in detecting variations when integrated into visualisation tools (Kindler & Martinson, 2024). The implementation of SPC in the visualisation tool yielded multiple statistical alerts, showcasing its success despite encountering limitations related to the thresholds of the control charts. Kindler and Martinson (2024) suggest that future researchers should establish precise thresholds in their control charts while highlighting the successful use of SPC in new contexts and its potential in enhancing visualisation tools.

3.3 QUALITY FUNCTION DEPLOYMENT

QFD is a quality focused planning process used during the early stages of product development (Bergman & Klefsjö, 2010). It integrates customers' desires and requirements, translating them into actionable product features to ensure the development process leads to customer satisfaction (Bergman & Klefsjö, 2010). Developed in the late 1960s by Yoji Akao and Shigeru Mizuno in Japan, QFD strives to ensure that customer needs are recognised and addressed throughout the organisation, from product planning to production (Bergman & Klefsjö, 2010).

By consistently prioritising customer feedback, QFD empowers companies to create products that is adapted to their target audience, enhancing customer satisfaction and loyalty (Bergman & Klefsjö, 2010). Bergman and Klefsjö (2010) continue to explain that QFD helps product development by identifying the most critical design elements, avoiding overengineering, and optimising the use of resources. Additionally, QFD encourages proactive risk management by pinpointing potential design conflicts early in the process, helping to prevent costly modifications. Overall, it provides an extensive framework that aligns product development with customer expectations, ensuring a more efficient, effective, and customer-focused outcome (Bergman & Klefsjö, 2010).

One of the main tools of QFD is the house of quality which provides a framework that correlates customer requirements to product characteristics, see Figure 5. According to Bergman and Klefsjö (2010), the house of quality encourages engineering, marketing, and production teams to prioritise customer requirements collectively, promoting a united approach to product design. By consistently prioritising customer needs voices, it improves satisfaction and loyalty. It helps the development process by identifying crucial design elements and preventing over-engineering (Bergman & Klefsjö, 2010). Moreover, by revealing potential design conflicts early, it mitigates risks in production.

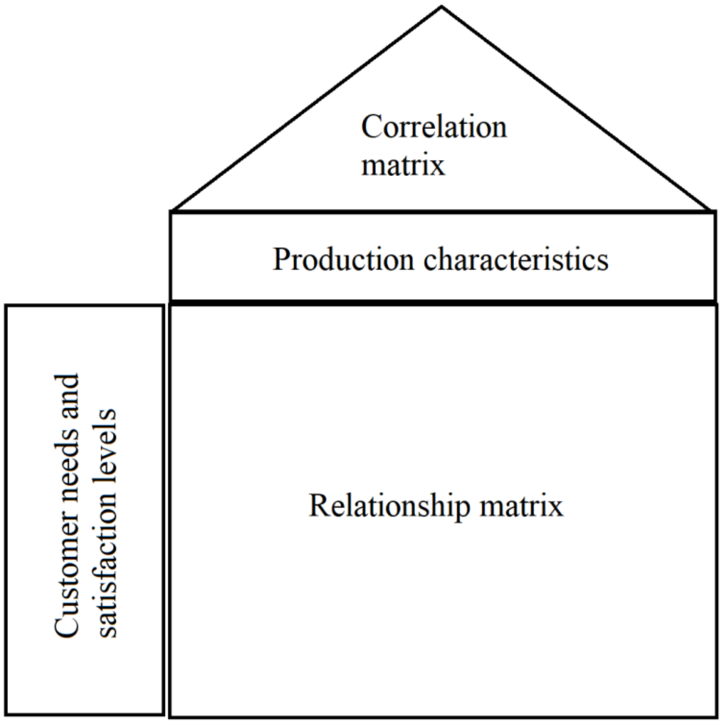


Figure 5: House of quality based on Bergman & Klefsjö (2010:129)

The house structure consists of four main areas according to Bergman and Klefsjö (2010):

- Customer needs and satisfaction level, deprived from previous research or surveys etc. Includes each needs importance level.
- Product characteristics, presenting how the different needs can be satisfied.
- Relationship matrix, how the different characteristics correlates to different needs.
- Correlation matrix, how the different characteristics correlate to each other.

In software development, QFD theory is limited and out of date, but not entirely unknown. According to Bernett and Raja (1995), QFD as a theory does not fulfil the specific challenges of software development. QFD lacks a structured way to understand customer needs in software and that the results of an QFD in software development results in defects (Barrnett & Raja, 1995). Bernett and Raja's (1995) proposition is to deploy the house of quality in QFD as a four-stage solution to tackle the current limitations in software development. By splitting the QFD house of quality into four aspects of software, one can more easily cover the different areas. They continue to explain that software development with QFD is limited to software that enable other processes, and not software that fulfils customer needs or is considered a final product (Barrnett & Raja, 1995).

3.4 EFFECTIVE VISUALISATION

Effective visualisation is rooted in the cognitive and perceptual sciences, focusing on how humans interpret visual information (Gandhi & Pruthi, 2020). Visualisation in itself is the process of transforming data, information, and knowledge into a visual form, making complex data understandable and actionable (Gandhi & Pruthi, 2020). This transformation is guided by principles that ensure the clarity, efficiency, and interpretability of visual representations. One of the principles of effective visual representation is clarity and simplicity, Tufte (2007) emphasises the importance of presenting information clearly and concisely. To avoid unnecessary decoration that can clutter the visualisation and confuse the viewer, users can use clean visuals and a minimalistic design to ensure a simple approach (Tufte, 2007). Another viewpoint is to optimise the data-ink ratio which is the ratio of informative and relevant data visualised divided by the total amount of data and information visible (Tufte, 2007). This concept advocates for the elimination of unnecessary graphical elements that do not contribute to the viewer's understanding.

The choice of colours and contrasts used in visualisation can affect the effectiveness tremendously by altering the readability or interpretability. Appropriate use of colour schemes can direct attention, indicate categories, and represent values accurately, without causing misinterpretations or visual fatigue (Sadiku, et al., 2016). Colour coding can also increase efficiency when reading data and visuals as colour stratification can increase the viewers reaction time (Wu & Xu, 2020). In addition to colour, the inclusion of interactivity in visualisation allows users to explore data more efficiently which leads to user engagement and a deeper understanding of the data (Peddoju & Upadhyay, 2020). Interactive features such as filtering, zooming or selection of elements will increase the viewers' engagement and understanding of the visuals presented.

4 PROGRAM SELECTION AND END USER SPECIFICATION

This chapter presents and analyses the first part of the results: program choice and end user expectations. These two parts interpretates the interviews to gain insight into the importance of the tool and its features.

4.1 PROGRAM CHOICE

The first step of visualisation tool development is to understand where the tool should be developed, making program choice the first step. Choosing a program for developing the tool involved brainstorming potential candidates based on the author's previous knowledge of visualisation tools actively used in the market. This search yielded candidates such as Excel, Microsoft Power BI, Microsoft Visio, Tableau, or creating a new one from scratch through programming.

The programs in which the visualisation tool could be developed were then compared to determine the best fit for Vattenfall. To efficiently compare the different programs, the seven most crucial attributes were compared and weighted on a scale of one to ten, where ten represented "most important." These attributes were developed during program selection interviews to understand which aspects are most important. This importance was discussions with stakeholders to gain an accurate rating for the attribute weighting. The attributes were:

- **Data Compatibility**

Data compatibility is crucial for visualisation tools as it directly impacts the efficiency, effectiveness, and overall usability of the software in generating meaningful insights from data. According to interviews with employees, the program must be capable of easily importing and processing data from the original data source that Vattenfall is already using. Compatibility ensures that users can quickly bring their data into the tool without needing extensive preprocessing or conversion, which saves time and reduces the risk of errors. In addition, when compatible with the original source of data, the tool can more effectively preserve the quality and integrity of the original data during the import process. This is essential for accurate and reliable analysis in according to Redman (2001). Tools that mishandle or incorrectly interpret data due to compatibility issues can lead to misleading visualisations, potentially resulting in poor decision-making (Redman, 2001). Poor data compatibility would require additional technical skill to ensure that the visualisation tool is accurate, this limits accessibility and the usability of the tool. By accommodating the original format of the data, the tool lowers barriers to entry, enabling more users to generate insights through visualisations (Redman, 2001). For these reasons, the weight of “Data compatibility” is set to a nine out of ten.

- **Usability**

Usability directly influences how effectively and efficiently users can turn data into actionable insights by assuring that common tasks are straightforward, and complex analyses can be performed with minimal effort, thereby enhancing productivity. High usability allows users to navigate and interpret visualisations without needing much training which makes the tool accessible to users with different level of skill (Tufte, 2007). Users will also more likely become engaged in the tool and use it to its full potential, leading to more innovative uses of the data and future improvements (Tufte, 2007). Interviews with employees made it clear that when users can easily navigate the software and achieve their objectives with minimal frustration, their satisfaction with the tool increases. This positive experience is crucial for ensuring long-term use and can influence the decision to further improve and implement the tools capabilities and uses. Usability is therefore weighted as a seven out of ten because it is highly important, but the employees can overcome the challenges of a lower usability.

- **Integration**

The interviews and observations gave the insight that both the program and the resulting visuals must be able to function in the organisation and be integrated in current processes. If the software cannot be integrated into the processes where stakeholders need it, then it will be of no use. Similarly, if the visuals cannot be easily used in documentation, PowerPoints or in similar tasks then they cannot effectively be communicated. Integrated visuals and relevant data become easily accessible and can lead to informed and improved data driven decision making (Redman, 2001). And because integrated visuals have no need for post processing, the data shown will be standardised which minimises any risks for error or miscommunication. It is also important for future developments and projects that the tool can easily be integrated with other tools so that it can be of use for a longer period of time. These factors are crucial to the project and are therefore weighed as an eight out of ten.

- **Customisation**

Customisation and customisable design enable the creation of visuals that are tailored to the specific context and audience, making complex data more understandable. According to the interviews it is important to ensure that different stakeholders can use the tool, the information needs to be able to be presented in a way that is understandable, ensuring that key insights stand out and are easily comprehended. Therefore, the program needs to be able to generate appropriate visualisation types, colours, and layout to accurately present the data. It needs to have the capabilities to show multiple different representations as the needs can differ for different stakeholders. Customisation is also important for future additions and updates as the interviewed employees have declared that they are interested in expanding the number of visuals shown by the tool. This feature is often mentioned by the interviewed employees as important which gives the attribute a weighting of seven out of ten.

- **Access**

Organisations do not always have full access to all programs that are viable. If Vattenfall does not have a license for a certain program, then future implementations will be limited if it is even considered. It is also not uncommon for organisations to have limited access to programs where only a few at a time can use them, which could prevent the usage of the tool. This includes the programs that are pre-installed. If installation of new software is required to be able to use the tool, then many might develop a resistance towards the tool. Having a wider spread of accessibility to the tool will also increase the amount of ongoing feedback that it receives, opening the way for future improvements. As lack of access would lead to lack of users being able to use the tool, it is apparent that its importance is high. Therefore, it is weighted as a nine out of ten.

- **Safety**

As safety is the most important aspect when comparing programs, many viable options cannot even reach the comparison stage. According to the interviews, a common risk in security is cloud-based software because a perpetrator could access the data remotely. This risk leads to the reasoning that only local options are allowed; any program that requires internet service cannot be used Another important factor is how the data is visible and if malicious users could alter the file locally which disturbs the use or integrity of the tool. The programs that are chosen as candidates are already screened for some safety issues to ensure that they have local option and is not fully cloud based. But it is still the most important category to compare which is why it is weighed as a ten.

- **Learning curve**

The time it takes to understand and be able to work with the program, for both users and the author as developer is crucial for the success of this project. As the thesis has a set scope and deadline, learning something from scratch could be a poor choice. If time runs out, some important features might not make the cut and in worst case, the entire tool gets scrapped. And for Vattenfall to start using the tool, a program that the users are already familiar with or that requires little to no training will remove any resistance or uncertainties concerning its uses. Therefore, programs that both Vattenfall employees and the author are familiar with is an important aspect and will save a lot of time. For this reason, the attribute is weighted as a seven.

4.2 RESULT OF VALIDATION

The result from the weighting and program comparison came from follow up program selection interviews with the results in Table 3. The end results were derived by multiplying each weight by its corresponding value and summing them up. Here the learning curve had a negative number as it has a negative impact on the program itself, the higher the learning curve the worse the program becomes. The calculations identified both Excel and Microsoft Power BI as leading contenders. The slight difference between them stemmed from two factors: the learning curve as Excel was more familiar to both the author and the employees than Power BI, and customisation capabilities as Power BI was being regarded as more adaptable and user-friendly choice. A brief comparison suggested that while Power BI would be the superior choice for the task, Excel could offer a faster and simpler solution due to its shorter learning curve.

Table 3: Multiple different visualisation programs compared to a set of criteria, which are weighted to gain a result.

	Category	Data Compatibility	Usability	Integration	Customization	Access	Safety	Learning curve	Result
	Weight:	9	7	8	7	9	10	-7	
Program/software	Excel	10	10	10	6	10	10	4	444
	Power BI	10	9	10	10	10	10	6	451
	Visio	7	6	8	7	10	10	6	366
	Tableau	9	7	6	7	6	10	8	325
	Programming (Matlab/Python)	10	6	7	10	7	10	10	351

As previous result noted, Power BI was regarded as the most suitable tool for the task, despite the potential for it to be time consuming. This concern was discussed with stakeholders and considered a worthwhile risk, given that features could later be implemented by their employees after integration. Additionally, an interview with one of the stakeholders highlighted that Power BI is increasingly being adopted in Forsmark's processes, reinforcing its selection as the preferred program.

4.3 FEATURES AND EXPECTATIONS

The interviews, subject "tool usage and potential", conducted with stakeholders gave vital information about the expectations of the visualisation tool and its features. The main areas used to guide the interview were to understand basic tool needs, stakeholders wish list, negative aspects of other programs, good and bad aspects of other Power BI projects and stakeholder understanding of effective visualisation. These interviews' structure was inspired by the Kano model to easily steer the conversation towards informative discussions. The answers were also directly placed into their respective kano category.

During "tool usage and potential" interviews, questions related to requirements and the work process generated multiple features that stakeholders considered essential for the tool to be of any use. These features were also necessary for the stakeholders work process which would potentially streamline their everyday work. The absence of any of these features would therefore reduce the tool's perceived value and effectiveness.

Must be features

- Must show the mean value of temperatures and radiations.
- Must show the max value of temperatures.
- Must show values over time.
- Must have access to historical data filtered by year.
- Must be relatively easy to continue to expand upon the tool with new variables.
- Must show a layout picture of the plant where the placement of all measure devices is presented.

During the interviews, when required features were discussed, and when other visualisation tools were compared to, some features were identified that would provide satisfaction but were not as critical as the must-be features. Features that improve the usage and usability of the tool, and that can increase the users understanding of the data within but that does not hinder the tools usage if not fully implemented. These features are highly important and will affect the total satisfaction of the outcome but are not critical, hence as theory by Löfgren and Witell (2008) suggests, they are categorised as one-dimensional.

One-dimensional features

- The tool and its layout should be compact.
- The tool and its layout should be easy to understand and navigate.
- The resulting visuals should be easy to put into power points or reports (easy to share)
- The data shown should be correlated to the measurement devices' hight and degree of position.
- There should be a control diagram of the mean values with control lines.
- It should be easy to find corresponding object identification number that is correlated to each measurement.

To gain a better understanding of stakeholder's vision, the author asked questions about features they would like to see if there were no restrictions. During these discussions only a few features were mentioned as the stakeholder wanted the must-be features. These features naturally fit the Attractive category as the stakeholder would gain satisfaction for if fulfilled but does neither know which one they want nor expects them to be fully implemented.

Attractive features

- The tool should show trendlines and values that can predict and potentially warn the users of new trends.
- There should be a search feature where you can search and categorise the data however the user likes.
- There should be a three-dimensional image of the plant where the data can be visualised at its actual position.

During the interviews, the author and stakeholders discussed the role of effective visualisation and colour stratification, but the stakeholders did not view these elements as influential to their perception of the tool. Consequently, features heavily dependent on these aspects were deemed **indifferent qualities** as their impact could not be reliably predicted from the interviews alone. But literature in the related work section highlighted that such features significantly affect users' cognitive abilities, as a result it would still be taken into consideration during development. This importance was further proved when stakeholders identified features in other programs that they found annoying or problematic. Their feedback focused on two main issues: visuals that were difficult to interpret, emphasising the need for clear visualisation, and the placement of raw data on the front page without context, which often led to confusion. Stakeholders further told the author that even if raw data is very important, it is common for visualisation projects to assume readers have the same knowledge of the data as the developers, which is not always the case. Raw data will therefore be categorised as a **reverse quality**, not because it should be removed but because the more it is shown, the more dissatisfaction it creates. These insights guided the prioritisation during the tool's development where “must-be” comes first, followed by “one-dimensional”, “attractive”, with the “indifferent” and “reverse” features last.

5 VISUALISATION TOOL DEVELOPMENT

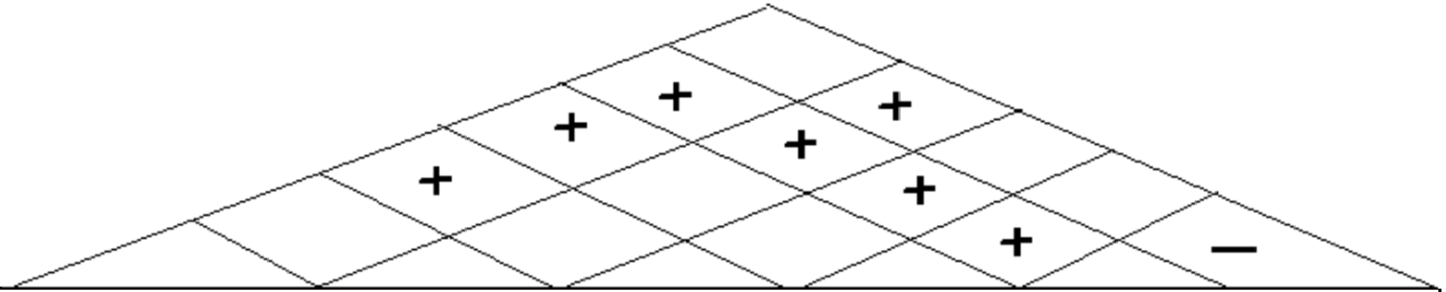
Here, the second part of the results are presented and analysed. These results consist of the entire process of the visualisation tool development from the end user expectation in the chosen program, following with some analysis of the data visualised. This chapter ends with a summary of all results, including chapter 4.

The tool development was split into three parts, the resulting functionality generated with QFD, a diagram used to aid the development, and finally the result from the creation of the tool itself. The tool will use simulated and anonymised data[1].

5.1 FUNCTIONALITIES FROM QFD

With the results of the Kano model, the end user requirements became known. To effectively translate these into tangible functions, a QFD house of quality was constructed, see Figure 6. As QFD is commonly used in product development, some adaptations were necessary to support the tool development for this thesis. Initially, the importance weighting was modified to align with the Kano model categories. The metrics compared were changed to functions, where the roof correlation illustrated how these functions impacted each other's compatibility or if they could assist in each other's development

[1] As information from nuclear power plants from Sweden requires a security clearance given by Swedish agencies, none of the data or specific information are allowed to be presented. Instead, simulated data and representative figures will be shown. The author has ensured that the simulated data shows similarities in trends and results to simulate the real results of the case study, but none of the numbers presented is true to reality.



QFD House of Quality	Attributes	Search engine that lets users put in data requirements and returns releted averages and historical data	Map of the powe plant whith measurment device locations placed out	Analysis page showing historical trends and possible data discrepancies	Have a seperated page with interactiv filterable raw data	Power BI as tool program	3D Map of the power plant where data is visualized as heat nodes
Requirements	Customer importance	Correlation matrix					
Must show the mean value of temperatures and radiations	Must-be	X		X			
Must show the max value of temperatures	Must-be	X					
Must show values over time	Must-be	X		X			
Must have access to historical data, aka filter by year	Must-be	X		X			
Must be relatively easy to continue to expand upon the tool with new variables	Must-be				X	X	
Must show a layout picture of the plant where the placement of all measure devices is presented	Must-be		X				
The tool and its layout should be compact	One-dimensional					X	
The tool and its layout should be easy to understand and navigate	One-dimensional					X	
The resulting visuals should be easy to put into power points or reports (easy to share)	One-dimensional					X	
The data shown should be correlated to the measurement devices' hight and degree of position.	One-dimensional	X					
There should be a control diagram of the mean values with control lines	One-dimensional			X			
It should be easy to find corresponding object identification number that is correlated to each measurement	One-dimensional		X				
The tool should show trendlines and values that can predict and potentially warn the users of new trends.	Attractive			X			
There should be a search feature where you can search and categorize the data however the user likes	Attractive	X					
There should be a 3D image of the plant where the data can be visualized at its actual position.	Attractive						X
Raw data available but not a hinderence	Reverse				X		

Figure 6: QFD house of quality with user needs and tool functions.

The outcome of the QFD indicated that six main functions were needed to fulfil the requirements from the end users. The first function addressed searchability, enabling users to input their own values to find analysis answers. The second function aimed to visualise the placement of each measurement device or node within the nuclear power plant. The third function involved general analysis, displaying trends, control charts, and other necessary values. The fourth function allowed users to access raw data, preferably in an interactive manner to avoid overwhelming them, as this would lead to dissatisfaction as it is a reverse quality. The fifth function represented the program selection which demonstrates how Power BI itself could influence user needs and other functionalities. Lastly, a three-dimensional map of the nuclear power plant was needed, showing data as a heatmap.

The "roof" correlation matrix revealed the resultant correlations between functions. Notably, the fifth functionality, which was the program choice, had a positive correlation with the first four functions as it had the capacity to support those functionalities. On the other hand, the sixth functionality which is the three-dimensional map, was not supported by the version of Power BI used in this thesis. This gave it a negative correlation and because it only affected an attractive quality it could be removed from any further development without hurting the overall satisfaction that the tool aims to fulfil. It did on the other hand have a positive correlation with the visualising of the node placements as they could have been integrated into the three-dimensional map. Furthermore, the functionality for searching with user inputs showed a direct positive correlation with both the analysis and raw data functions. This was because it made the analysis more adaptable to user circumstances, and the raw data would no longer be overwhelming as users could search for their specific data points. Both of these would lead to fulfilling user needs and increase satisfaction.

5.2 THE VISUALISATION TOOL DEVELOPMENT

Following the results from the QFD, the first task was to translate the identified functionalities into a practical visualisation tool. The initial step involved strategically planning the development by mapping out user navigation and interaction with the tool, see Figure 7. The diagram results suggested that the tool should be divided into three main areas: analysis, raw data, and measurement node placements. The analysis section was designed to include charts and information that would offer insightful interpretations of the data, tailored to meet the end user needs identified by the Kano model results. The raw data page was planned to be a search platform where users could locate specific datasets. Lastly, the measurement node placement page was designed to be an interactive map of the reactors, where users could view the node placements and related information. This diagram served as a blueprint for the remainder of the development process.

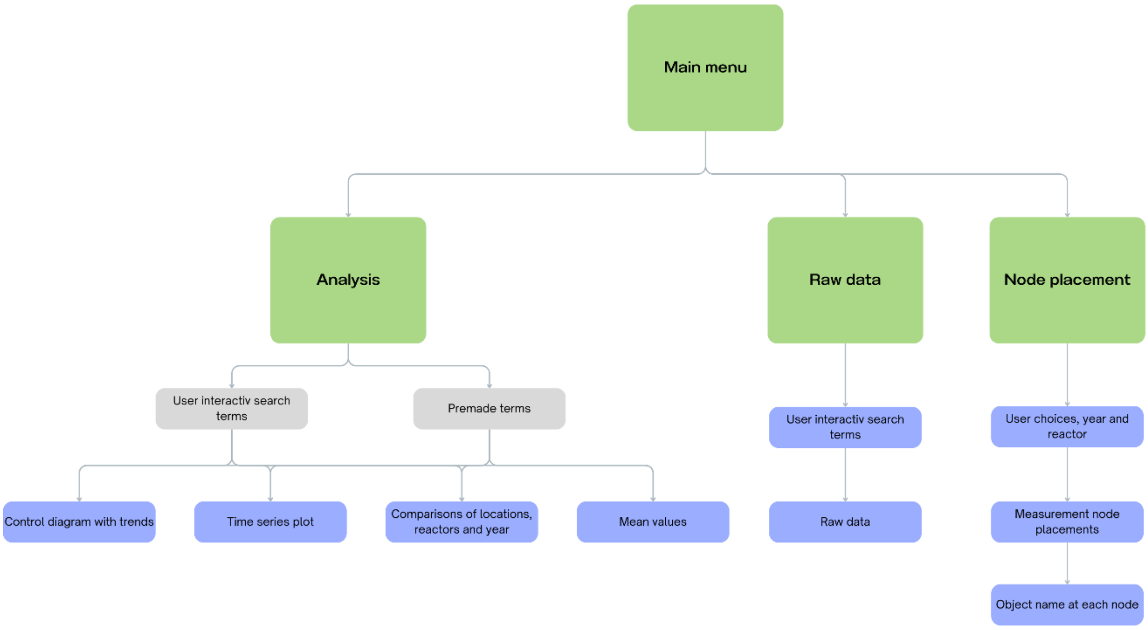


Figure 7: The planning diagram of the tool showing how users were meant to use the tool.

5.2.1 Main page and navigation

The first page resulted in a main navigation page that presented users with the title of the tool and navigation options to the different pages the tool offered, see Figure 8. Additionally, a string of information was strategically placed on the main page with a red exclamation point to gain users attention. The information informed users on how to use the navigational buttons and other interactive features within the tool's pages. The main page's purpose was to ensure that users were not overwhelmed by information and visuals immediately while providing aid in navigation so that users could easily find what they were looking for. The page was designed to be simple and initiative, as effective visualisation theory suggested. This page effectively contributed to fulfilling two one-dimensional customer needs:

- *The tool and its layout should be compact.*
- *The tool and its layout should be easy to understand and navigate.*

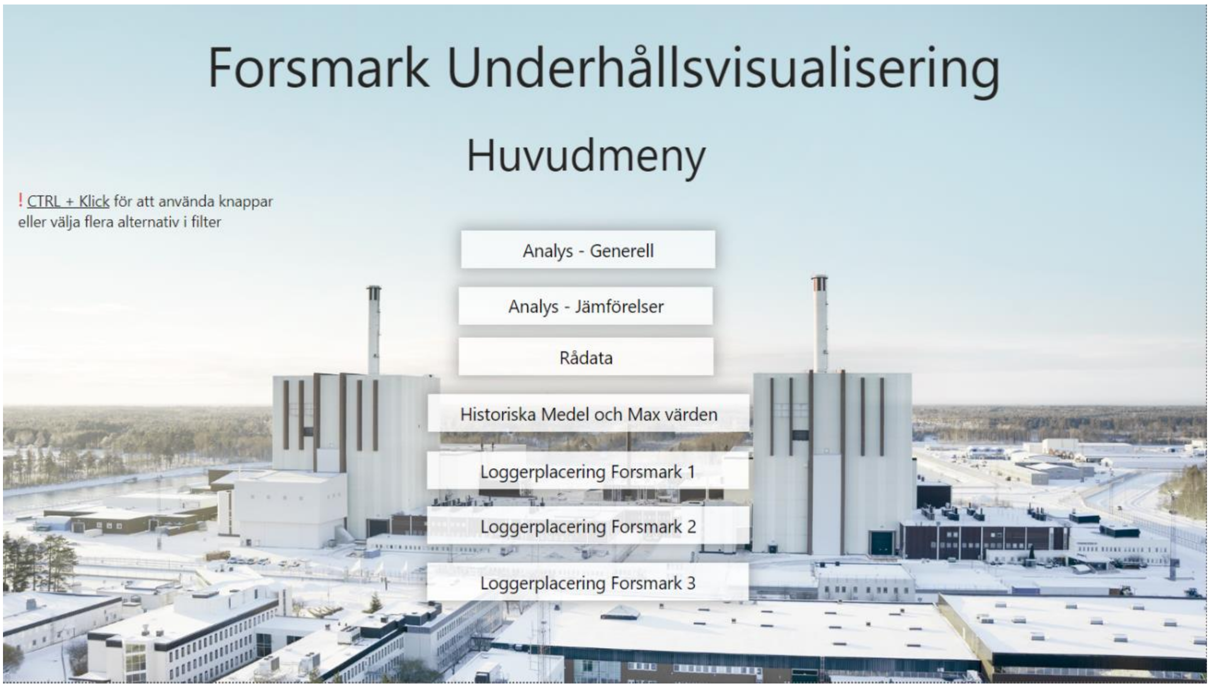


Figure 8: The main page, see Appendix A for translations.

The choice of background for the main page had its own intentions. As the tool was tailored to the needs of the nuclear power plant at Forsmark, as presented in the Kano model, it was also designed with regard to their process and workspace. This was achieved using a background image provided by Vattenfall's publicity department to represent the nuclear power plant. Furthermore, the navigation options on the page were designed to change when users hovered their cursor over them to visualise which option users were clicking. It is important to note that there were changes during the development process as the current navigation options differed from those originally planned as shown in the development planning diagram. Despite these modifications, the options continued to fulfil their intended functions, see Table 4.

Table 4: The split navigational options in relation to the planned options

Navigation name	**Relation to tool diagram**
Analysis – General	Analysis
Analysis - Comparison	Analysis
Historic means	Analysis
Raw data	Raw data page
Logger placement Forsmark 1	Measurement node placement
Logger placement Forsmark 2	Measurement node placement
Logger placement Forsmark 3	Measurement node placement

The pages presented in the tool included two additional navigation features: a home button that allowed users to return to the main page if they wished to navigate to a new page, and a link to the raw data page. This design decision was influenced by feedback from employees during development, who frequently asked, "What if I wanted to know more about a certain data point, node, or measurement?". The navigation to the raw data page made it easier for users to quickly look up any specifics they needed. To further enhance usability, a return button was implemented on the raw data page, enabling users to easily go back to their original page after checking the details.

5.2.2 Analysis pages

During the development of the analysis pages in the tool, the author identified the need for distinct types of analysis, leading to their categorisation into three specific groups. These were defined as “Analysis General,” which included control diagrams, trends, and measurement differences in reactors and nodes; “Analysis Comparisons,” which involved data comparisons between floors and quadrants; and lastly, “Historic Means,” which presented the history of the mean values for all values. With these analysis pages, the following user requirements from the Kano model were fulfilled:

- *Must show the mean value of temperatures and radiations.*
- *Must show the max value of temperatures.*
- *Must show values over time.*
- *Must have access to historical data filtered by year.*
- *The data shown should be correlated to the measurement devices' hight and degree of position.*
- *There should be a control diagram of the mean values with control lines.*
- *The tool should show trendlines and values that can predict and potentially warn the users of new trends.*

There were one need that was only partly fulfilled:

- *There should be a search feature where you can search and categorise the data however the user likes.*

The reason this need only were partly fulfilled is because of “however the user likes” part of the end user need. The analysis implemented the functionality for users to write their own values, but the scope of those values and categories that can be filtered were limited and therefore cannot fulfil the “however the suer likes” part of the need.

Analysis general page

The Analysis General page in the tool resulted in a presentation of averages for the three reactors, a control diagram, trendlines, control rule warnings, comparisons between reactors, and differences between node values, see Figure 9. There were three versions of the page, see Appendix C and Appendix D for the other two, depending on the data the user wanted to analyse: temperature averages, maximum temperature, and average radiation dose. Users could switch between these categories using top buttons that also indicated the current page by turning blue and changing the page title. This design helped ensure that users knew which page they were on, reducing the risk of misunderstandings.

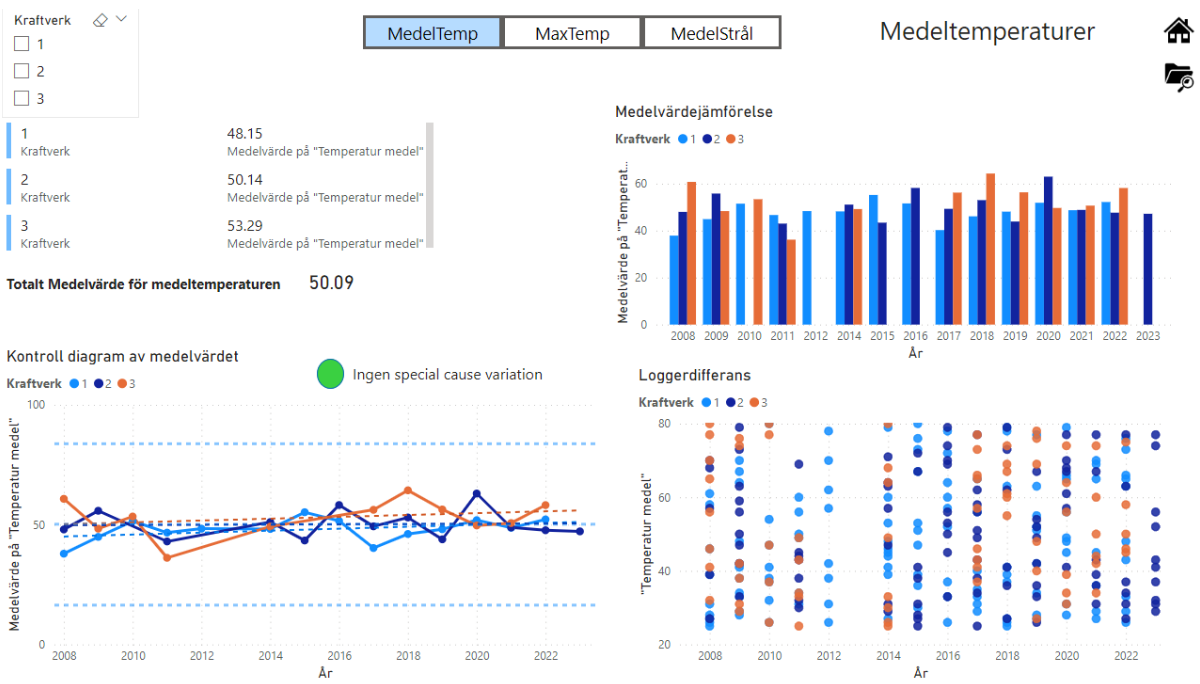


Figure 9: Analysis general page for average temperatures, see Appendix B for translations.

This page aimed to help users understand the differences between the three reactors at Forsmark. It allowed users to select which reactors to compare, automatically adjusting the display based on user choices. When a reactor was selected for investigation, the others turned transparent, leaving only the relevant data visible, see Appendix E. If multiple reactors were selected, their data would also be visible. This increased user interactivity, ensuring that users could compare and analyse the data they were interested in. The data results did not show any apparent trend or pattern, except that the third reactor generally had higher temperatures and radiation levels, which might be due to its significant differences from the other two as the data suggested.

Another result that the page included was the control diagram, which showed the selected reactors' values for comparison. It automatically checked if the data was in control or if there were any special causes, turning the green circle red and writing which rule that was broken. In this instance, there were no special causes, and all data was in control. The control diagram also featured trendlines that indicated positive trends in every measurement category for each reactor, suggesting an increasing mean in all values. This was a concern that Forsmark employees had been informed about and would be investigated further, although the data for radiation might have insufficient evidence due to a lower number of data points.

The comparison of nodes gave users the ability to see if any node was an outlier in the data. The visual could also provide the node number in case of an outlier, enabling users to navigate to the raw data page, find the specific year and node, and better understand its location, nearby objects, and other information. In this instance, there were no outliers that needed investigation, but the capability to do so remained available for future data.

Analysis comparison page

The analysis comparison page resulted in a presentation of average values for the different floors and quadrants measured within the reactors, see Figure 10. Similar to the first analysis page, there were three categories for the main measurements analysed: average temperatures, maximum temperatures, and radiation doses, with clear indications of which measurement the user was currently viewing, see Appendix G and Appendix H. The purpose of this page was to enable users to compare specific positions with each other and between different reactors. It helped clarify the relationships between floors and quadrants for future projects and provided insights into how radiation and temperature spread within the reactor. Users could compare using the given parameters or use sliders to input specific values and compare these particular areas. This flexibility allowed the page to accommodate both general comparisons and specific user needs as they arose.

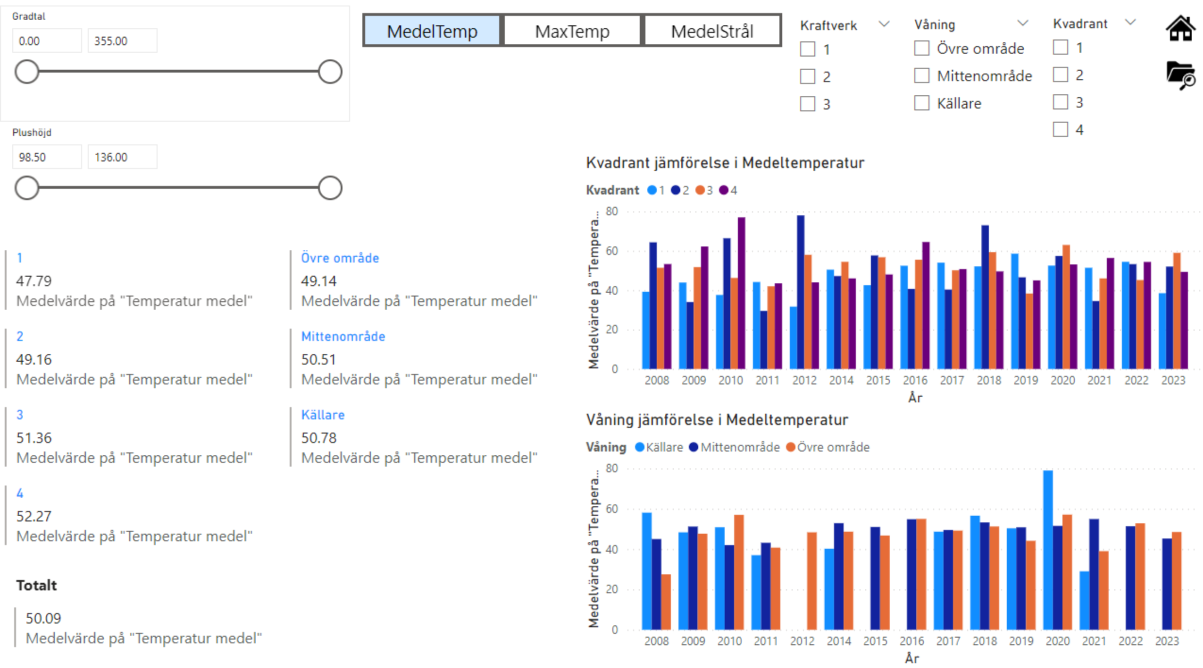


Figure 10: The Analysis comparison page for average temperatures, see Appendix F for translations.

The data showed that the average temperature generally increased on higher floors, although the maximum temperature remained largely the same across levels and that the basement level exhibited lower radiation levels compared to other floors for multiple reactors. If explored further with the interactive features, many similar findings were found but all these results were already known to Vattenfall employees and did not result in new insights.

Historic means

The historic means page displayed key statistical averages for average temperatures, maximum temperatures, and radiation doses over the years, see Figure 11. It also highlighted the peak values observed, such as the highest average temperature, maximum temperature overall, and highest measured radiation dose, providing insights into the potential heat and radiation levels in the area. The page featured user-friendly design elements, including fully interactive sliders that allowed users to set specific values for detailed analysis. For those who preferred a broader overview, premade categorisations for floors and quadrants were also available.

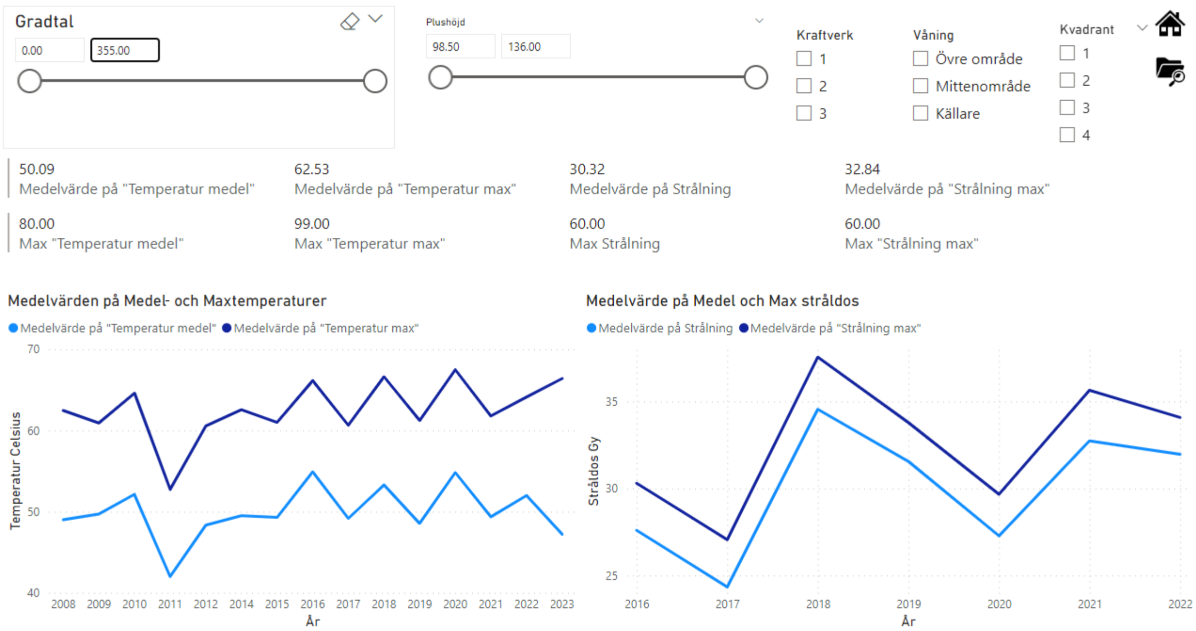


Figure 11: The historical means page, see Appendix I for translation.

While this page primarily served to document historical averages and did not offer much new information or data analysis, it did uncover an anomaly previously unknown to Vattenfall employees. In one particular year, shown under the year 2023 in Appendix I, the mean temperature significantly dropped while the maximum temperatures notably increased. The cause of this discrepancy remains unclear. However, after discussions with employees, it was determined that the anomaly, having minimal impact on the overall environment and possibly resulting from measurement errors or statistical anomalies, was not a major concern.

5.2.3 Node location page

The node placement page featured maps and structural blueprints of the power plant reactor floors, with each measurement point indicated by a dot, see Figure 12 and Appendix K and Appendix L for the other reactors. On this page, users could choose which reactor to explore using buttons at the top. These buttons mirrored those on the analysis pages, creating a cohesive interface that made it easy for users to recognise its function and to easily identify which reactor they examined. Users could also select one or more years to review or select the slider to see all nodes. By selecting certain years, the visual temporarily hid unrelated nodes, highlighting only those related to selected years. Additionally, users could hover over any node to reveal the data logger number and the specific object the measurement device was related top. This functionality was key for accurately locating measurement points and assessing where new measurements might be necessary. Furthermore, after communicating with non-senior employees, the node location page helped with identifying both objects location but also identifying key locations within the reactors. Meaning future learning of reactor positions have become an easier task.

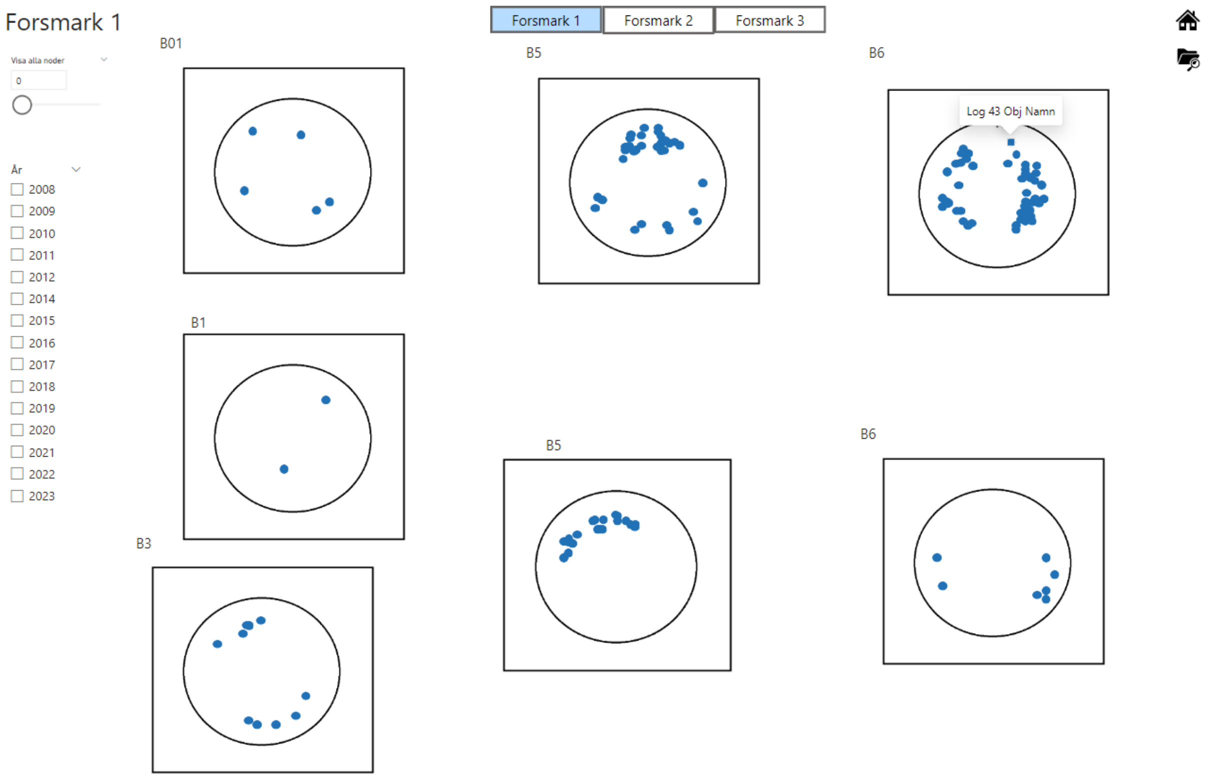


Figure 12: Node location page, see Appendix J for translations.

The end user need from the kano model fulfilled was:

- *Must show a layout picture of the plant where the placement of all measure devices is presented.*

And partly fulfilled need was:

- *It should be easy to find corresponding object identification number that is correlated to each measurement.*

As the node location page only showed where each object where but not related to its exact measurement data.

5.2.4 Raw data page

The main goal of the raw data page was to present measured data in a manner that was both effective and intuitive, ensuring that users could easily comprehend the information without feeling overwhelmed, see Figure 13. To accomplish this, the data was organised into a responsive list that automatically categorised and sorted entries according to the two main categories: the year of data collection, and the type of reactor involved. As a result, users could efficiently pinpoint specific data points for detailed analysis and retrieve relevant information. This enabled a smoother user experience but also significantly improved the accessibility and usability of data available. This page successfully prevented the access to raw data from being a reverse quality and instead increased end user satisfaction. At the same time, this page completed the need that the node location page only partly fulfilled:

- *"It should be easy to find corresponding object identification number that is correlated to each measurement."*

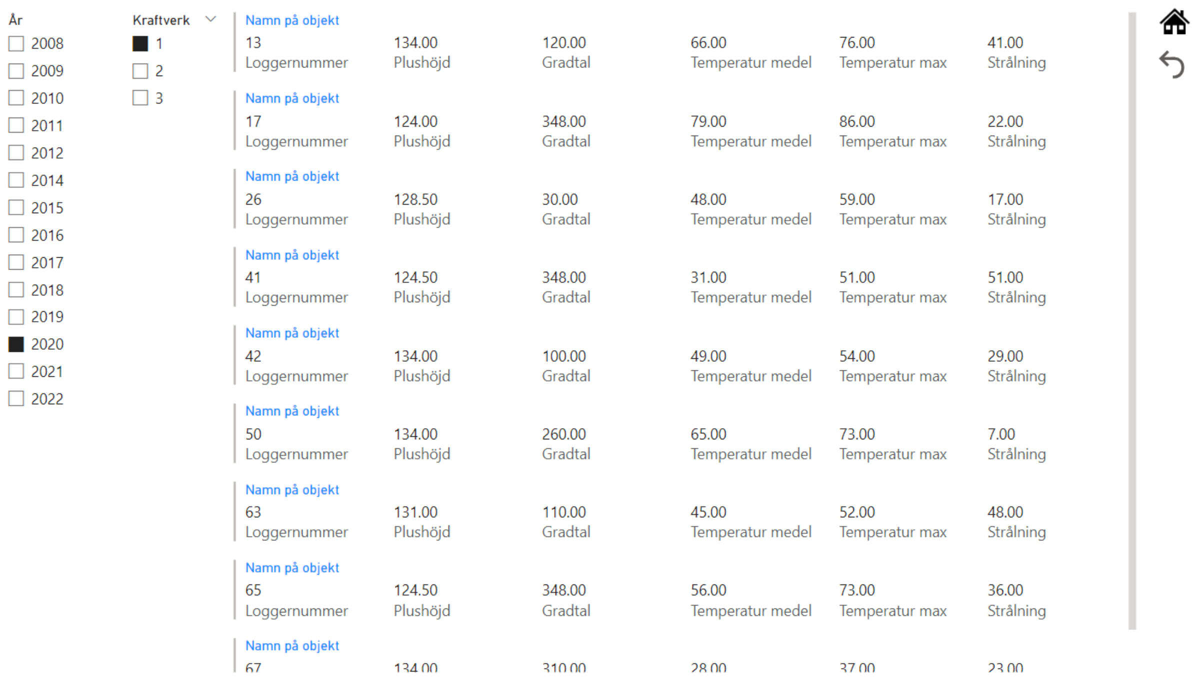


Figure 13: The raw data page, see Appendix M for translations.

5.2.5 User guidance and program effect on user needs

After the tool pages was developed, two end user needs were still in need of reflection:

- *Must be relatively easy to continue to expand upon the tool with new variables.*
- *The resulting visuals should be easy to put into power points or reports (easy to share)*

Both requirements were focused more on the software's capabilities rather than the visuals within the tool itself. During the program selection phase, these needs were taken into account by evaluating the integration capabilities. Power BI, a Microsoft product, naturally offers excellent compatibility with other Microsoft applications like PowerPoint, meaning that the second requirement was already satisfied by the program selection. The first need was addressed in two parts: the program selection, as Power BI is a tool that is highly intuitive and easy to expand upon, and through a user guidance document, see Appendix N. This guide clearly explains the basic steps of adding new data and how Power BI updates, new node placements and how to program the nodes to be compatible to user interactions, and how to modify or add new graphs and diagrams for future expandability.

5.2.6 Overall design strategy

The theory of effective visualisation was brought up by the author during interview to see if its concept were known and expected, but the result showed that following a set of visualisation rules did not affect satisfaction directly, yet the end users communicated the importance of understanding the tool. If the tool cannot be understood effectively it might hinder the work process instead of helping it.

The resulting tool were developed with a design strategy according to three main points of effective visualisation theory. Colour choices, avoidance of unnecessary decorations and integration of interactivity. The colours used in the visualisation tool were chosen to be uniformed to create a cohesive feeling between pages. On the pages themselves the colours were chosen to be distinctively different to ensure effective comparison. As the tool were created for Vattenfall AB, some brand affiliation choices were made such as the background image on the main page and some colour choices being brand colours. The reason that the tool had multiple pages instead of putting everything into one were a direct design choice based on decluttering. Furthermore, interactivity and filters ensured that comparisons were decluttered when users would want them to be. These choices effectively visualised the data on the tool's pages and helped fulfilling the end user means of "*effective visualisation*", "*The tool and its layout should be compact."* and "*The tool and its layout should be easy to understand and navigate.".*

5.3 SUMMARY OF RESULTS

A summary of all the results presented, including chapter 4.

5.3.1 Program selection summary

During the selection of program for Vattenfall's visualisation tool, multiple options were evaluated, including Excel, Microsoft Power BI, Visio, Tableau, and custom solutions such as programming from scratch. Critical attributes like Data Compatibility, Usability, Integration, Customisation, Access, Safety, and Learning Curve were assessed based on stakeholder inputs. Data Compatibility and Access emerged as key factors for their impact on tool efficiency and accessibility, while Safety's importance led to a set rule for locally managed solutions. Microsoft Power BI was ultimately chosen over others for its superior adaptability and customisation capabilities, aligning well with Vattenfall's long term objectives and administrative evolution, despite the runner up Excel being simpler and easier to learn for both employees and the author.

5.3.2 Kano model summary

During stakeholder interviews for a new visualisation tool, key insights were collected to determine the tool's features and development priorities. Stakeholders identified essential "must-be" features such as displaying temperature data, historical access, and expandability. They also suggested desirable but non-critical "one-dimensional" features like a compact layout and data correlations. Additionally, "attractive" features like trendlines and three-dimensional visualisations were considered to add value but were not essential. Stakeholder feedback also highlighted the importance of avoiding common pitfalls like poor visuals and data placement found in other programs. This feedback led to a feature prioritisation strategy based on the Kano model categories were must-be came first, followed by one-dimensional, attractive, indifferent and reverse qualities.

5.3.3 Tool development and Functionality Overview summary

The tool's development process began with the establishment of necessary functionalities through the QFD process, where end user needs were translated into tangible functions. The QFD house of quality identified six main functions required by the tool, including searchability, data visualisation, general analysis, raw data interaction, software selection, and a three-dimensional mapping of the plant. However, the three-dimensional mapping was eventually excluded due to software limitations.

Following the QFD analysis, a comprehensive planning diagram was created to translate identified functionalities into a practical visualisation tool. This included three main sections: general analysis, raw data access, and measurement node placements, each tailored to specific types of data interaction and analysis.

5.3.4 Page-Specific Functionalities

- **Analysis Pages:** Divided into three categories, General Analysis, Comparison Analysis, and Historic Means. These pages cater to different analytical needs:
  - **General Analysis:** Offers insights into temperature average, temperature maximum, and radiation values across different reactors, including trend analysis and control diagrams.
  - **Comparison Analysis:** Enables detailed comparisons of data across different floors and quadrants within the reactors, highlighting locational variations in temperature and radiation.
  - **Historic Means:** Focuses on long-term data trends, showing average and peak values over the years.
- **Node Location Page:** This page displays structural blueprints and maps of the plant, with measurement points indicated for easy identification. Users can filter these points by reactor and year, enhancing the tool's interactivity and utility in locating measurement devices.
- **Raw Data Page:** Aimed at presenting raw data in an organised and accessible manner, this page categorises data by year and reactor, allowing for efficient retrieval and analysis of specific data points. This design significantly enhances the user experience by preventing information overload and improving data usability.

5.3.5 Data findings

- The third reactor consistently generated more heat and radiation compared to the first two reactors, but as the third reactor were established as highly different than the other two, these findings were disregarded.
- Across all reactors, there was a positive trend in both temperature and radiation levels, suggesting a gradual increase over time. But, all data remained within control limits, indicating that these increases were within expected operational parameters.
- Historical data analysis highlighted an anomaly for the year 2023, where the mean temperature significantly dropped while the maximum temperatures increased. Despite this, it was considered to have a minimal impact and was attributed to possible measurement errors or statistical anomalies.

5.3.6 User Interaction and Satisfaction

Each page is designed with user interaction in mind, featuring intuitive navigation that mirrors across all pages for consistency. The tool also includes functionalities such as a home button and direct links to raw data, guided by feedback from development stages to enhance user navigation and data retrieval experiences.

5.3.7 Software and Expansion Capabilities

The choice of Power BI as the program for the tool's development was strategic, leveraging its compatibility with other Microsoft applications to ensure easy integration into reports and presentations, fulfilling requirements from stakeholders.

Additionally, a user guide was developed to ensure future expansions of the tool were possible and intuitive, instructing users on how to add new data and modify existing functionalities to adapt to evolving needs.

5.3.8 Kano model fulfilment summary

The end user needs were almost all fulfilled by the tool created. One of the attractive needs could only be partly fulfilled, "*There should be a search feature where you can search and categorise the data however the user likes*.", as a search feature could be implemented but had restrictions which limited the search usage. There was also one attractive need that could not be fulfilled at all, "*There should be a three-dimensional image of the plant where the data can be visualised at its actual position.",* as the program choice of Power BI and the version used for this thesis was limited to two dimensions. Table 5 shows the kano category with related user needs and how these needs were fulfilled.

Table 5: Kano model category and related user needs presented with how they were fulfilled during the thesis.

Kano category	End user needs	Fulfilment feature
Must-be	Must show the mean value of temperatures and radiations.	Analysis page
Must-be	Must show the max value of temperatures.	Analysis page
Must-be	Must show values over time.	Analysis page
Must-be	Must have access to historical data filtered by year.	Analysis page
Must-be	Must be relatively easy to continue to expand upon the tool with new variables.	Program selection, user guide
Must-be	Must show a layout picture of the plant where the placement of all measure devices is presented.	Node placement page
One-dimensional	The tool and its layout should be compact.	Overall, Main page
One-dimensional	The tool and its layout should be easy to understand and navigate.	Overall, Main page
One-dimensional	The resulting visuals should be easy to put into power points or reports (easy to share)	Program selection
One-dimensional	The data shown should be correlated to the measurement devices' hight and degree of position.	Analysis page
One-dimensional	There should be a control diagram of the mean values with control lines.	Analysis page
One-dimensional	It should be easy to find corresponding object identification number that is correlated to each measurement.	Node placement page, raw data page
Attractive	The tool should show trendlines and values that can predict and potentially warn the users of new trends.	Analysis page
Attractive	There should be a search feature where you can search and categorise the data however the user likes.	Analysis page - Partly
Attractive	There should be a three-dimensional image of the plant where the data can be visualised at its actual position.	None
Indifferent	Effective visualisation	Overall
Reverse	Overwhelming raw data	Raw data page

6 DISCUSSION

The discussion chapter gives the authors view on results in the context of the research questions and how well the result follows theory. The chapter ends with a conclusional summary and recommendations for further research.

6.1 HOW CAN QUALITY TOOLS EFFECTIVELY IDENTIFY AND ADDRESS THE NEEDS OF END USERS IN THE DEVELOPMENT OF A VISUALISATION TOOL IN A NUCLEAR POWER PLANT?

The findings of this thesis reveal that quality tools typically reserved for manufacturing are adaptable to these unique conditions. The Kano model proved to be able to retains its effectiveness when applied in a new environment and in a software development related project. The model successfully found multiple end users needs that fit the model's categorisation. Similarly, the QFD, traditionally designed for product development, was still beneficial in software development. By exploring correlations early on, contrariety features could be accounted for before they could become an issue. SPC control chart used in the tool could enhance data analysis efficiently even in a new context of nuclear power plants. These quality tools significantly improved the structure and efficiency of the tool development researched in this thesis. Their implementation led to a tool that nearly met all end user needs and expectations, developing a satisfactory result.

6.1.1 Kano model

The Kano model was used to categorise and prioritise end user needs and was a strong foundation for the tool development process in this thesis. The model proved highly effective in capturing user perspectives and requirements early on, as theory by Löfgren & Witell (2008) suggetsed. By keeping these categories in mind during interviews, the author could steer discussions to gain necessary or specific insights in areas otherwise hard to explore. The structure of the model increased the author's understanding of the role the tool would have in the process and why the end user needs were important, as supported by Witell and Löfgren (2007). The Kano model also helped prioritise the needs so that the development could continue with a structured approach. This prioritisation could also be communicated clearly to stakeholders and was easy to explain to those without prior knowledge, increasing end users engagement in the development without any confusion. The model could also serve as a checklist during development so that all identified needs were addressed. Additionally, by identifying attractive features early, the author was able to think outside the box and be more creative with the development. These innovations increased user interaction and satisfaction with the developed tool, which in turn improved the potential of the tool.

However, the theoretical limitations of the Kano model were evident during the categorisation process. Deciding which feature belonged in which category was ultimately the author's decision, even though influenced by end user feedback, making the prioritisation somewhat subjective just as Mikulic & Prebežac (2011) had warned. The boundaries between categories were not always clear, raising the question about whether user satisfaction depends more on functionality or usability. For example, the user need "The tool and its layout should be easy to understand and navigate" could be interpreted differently. On one hand, this need is not essential for the tool's functionality and the tool could still meet process requirements without it. But the more the need is fulfilled the more satisfactory the usage of it generates, meaning it is one-dimensional. But if the need is unmet, it might completely deter end users for adopting the tool, and if the tool is not going to be used then the other functionalities lose importance, making the need a must-be feature. The need is therefore not linear and does not fully fit any of the categories the Kano model presents but instead could be a combination of two. The need may initially be a must-be and later transition to one-dimensional as fulfilment increases.

These results can be compared to those of Kern and Refflinghaus (2018), who argue that satisfaction in software development is subjective and does not follow the original five levels presented in the Kano model. While Kern and Refflinghaus argues for individual categorisation based on variations of user satisfaction, this thesis suggests that the context of the features themselves may influence satisfaction levels, potentially requiring an overlap of categories rather than strict individual classification. A major difference between the research of Kern and Refflinghaus and the work presented in this thesis is the scope of application. Kern and Refflinghaus (2018) aim for a general approach, while this thesis focuses on a specific process adapted to specific individuals. Despite these differences, the similarity in findings shows the need for future research on adaptations of the Kano model and highlight the importance of considering individual and contextual factors in software development.

6.1.2 QFD

The QFD house of quality served as an effective translator of end user needs into actionable features, providing this thesis with a clear framework for the tool development, as Bergman and Klefsjö (2010) suggests. By aligning feature creation with the insights from the Kano model, the author could quickly identify starting points for the development and ensure that all end user needs were considered. It also offered an early overview of how the needs could be interconnected and addressed collectively, giving a foundation for an innovative approach. The framework could also identify correlations between the features themselves which led to intertwined solutions and a nonfunctional feature that had to be scrapped. Identifying that certain features and needs could not be met early in the process saved significant time, which would have been lost if these issues were discovered later in development.

The outcomes of the QFD in this thesis were aligned with Bergman and Klefsjö's (2010) theories. But it became noticeable that the QFD is generally more suitable for physical product development, as finding correlations between program functionalities in software projects can be difficult. Correlations could vary based on both the project scope and the developer's knowledge of tool development. Take for example the removed feature of three-dimensional mapping in correlation to Power BI, experienced developers might know workarounds, methods or complementary features making the correlation a subjective result. In physical production where constraints are often due to physical laws, correlations have a higher grade of objectivity and not as affected by the developer. Therefore, a version of QFD specifically for software development would likely be more effective for this task, allowing for better adaptation to the challenges of software projects.

The argument presented by Barrnett and Raja (1995) aligns with the findings of this thesis, that QFD needs to be adapted for software development. This thesis demonstrates that correlations in QFD are subjective, supporting Barrnett and Raja's (1995) statement about the unreliability of using the original QFD in software development. However, their proposed framework is not suitable for software used as end products, which this thesis has (Barrnett & Raja, 1995). Their solutions are therefore not applicable to the methodology used. The limitations of their framework and the age of their research highlight the clear lack of current studies in this area. This thesis offers a different adaptation of QFD by using it to visualise the translation of end user needs into features and then checking correlations, ensuring that software development does not rely entirely on QFD outcomes. By employing QFD as a support tool rather than as the primary development plan, the limitations and challenges discussed by Barrnett and Raja (1995) are somewhat obsolete.

6.2 HOW CAN A QUALITY-BASED VISUALISATION TOOL IMPROVE THE VISUALISATION PROCESS AND INCREASE THE UNDERSTANDABILITY OF THE CURRENT DATA IN A NUCLEAR POWER PLANT?

The resulting tool presented multiple layers of data visualisation and presentation, improving the process of visualisation and data understanding at Vattenfall. It provides insights into previously unrecognised trends and anomalies, indicates measurement locations, and assists those with limited experience in navigating the data. Additionally, the tool simplifies the process for employees needing to understand temperature or radiation levels within the reactors and the key locations these measurements represent, saving considerable time by eliminating the need to manually find and analyse data.

Throughout this thesis, the current process of data visualisation and analysis showed inefficiencies and lack of standardisation. Each year's data were stored in PDF files, and if an analysis were needed, Vattenfall would often re-collect data through new measurements or by going through old files creating a new analysis each time. This process was highly inefficient and time consuming, but the new tool now allows for immediate access to similar insights and more, transforming data interaction at Vattenfall.

The success of this tool has a definite connection to effective visualisation, SPC, and the selection of Power BI as the visualisation platform. These elements ensured that not only were the visuals insightful, but they were also understandable and interactive. By effectively presenting analytical components, the tool creates new insights and significantly enhanced the overall understandability of the data and the monitored areas.

6.2.1 Effective visualisation

During development, three main factors were prioritised as recommended by theory and related work: colour choices (Wu & Xu, 2020), decluttering (Tufte, 2007), and interactivity (Zhang, et al., 2021). These factors increased the tool's effectiveness, understandability, and functionality. By continuously having effective visualisation theory in mind during development, the process of creating visuals became based on more theoretical design choices, minimising the need for redesigns. Whenever a design choice was required, the author could use effective visualisation theory to quickly make informed decisions. During the development of the analysis page, the decision to split the page into two categories and then again split it in depending on the data used were directly influenced by Tufte‘s (2007) data- ink ratio mind-set. If all of that information were displayed on the same page, the reader would need to be guided through the page just to understand what they were looking at. But with the pages split, the suer can intuitively understand what the data presents. Likewise, the interactivity included in the tool ensured that multiple analysis graphs and comparisons could all fit in one page without disturbing each other. It could also provide specific information for specific tasks which further improves the usability and therefore the understandability, as Zhang et al (2021) suggest. When it came to colour choices, Wu and Xu (2020) recommended stratification to increase understandability, here the author took inspiration and ensured cohesive colour choices that are easy to distinguish from each other. If no thought were to be put on colour choices, then the graphs would be harder to interpret and there would be confusing to switch between pages. This made the development even more efficient and ensured that final product would greatly improve end users' ability to understand and interpret the data.

The results shows that effective visualisation theory is correlated with continuous improvements and quality management. The ability to clearly communicate analysed data is essential for ensuring that stakeholders comprehend the information, which is a critical success factor of quality projects (Unwin, 2020). Given the reliance on data-driven decisions in many continuous improvement initiatives, particularly in our data-driven age, improving the clarity and comprehensibility of data is increasingly vital. Therefore, being proficient in effective visualisation could be considered a continuous improvement of one’s quality management skills. Effective visualisation in practise were a difficult but important factor when creating the tool. Although the end users did not have a specific satisfaction threshold for the theory of effective visualisation, they emphasised the need for the tool to be user-friendly and intuitive. Unlike more structured quality tools, the theory of effective visualisation does not follow a straightforward framework, making it challenging to ensure the effectiveness of the visuals created.

6.2.2 SPC

SPC had a limited use in this thesis as only the control diagram was used, but it did still have an impact on the satisfaction that the tool created. The control chart used in the visualisation tool does provide an overview of the data and by setting control lines, it can effectively communicate, as suggested by Montgomery (2019) to the users that the process is in control and does not have any major fluctuations. As control diagrams were specifically asked for by the end users, their existence became highly important and helped create a fulfilling analysis of the data. It also means that the personnel already have some knowledge of statistical control systems and rules, meaning that further improvements to the analysis is probable. Even if personnel with SPC knowledge were to no longer be involved, the addition of automatically detectable control diagrams and the understandability of the rules ensures that any future warning will be heard and understood.

But the reliability and accuracy of these control measures are debatable, as data collection occurs annually. This interval does not account for intra-year variations, potentially allowing special causes to persist unnoticed for months before an alert is issued by the tool. The nuclear power plant does already have many safety measures in place and this tool is not one of them. But the tool is effective in noticing yearly trends that real time safety measures might not notice. These capabilities highlight the control diagram features in complementing existing safety measures by offering a long-term analytical perspective. But as discussed by MacCarthy and Wasusri (2002), inconsistencies in the data can lead to inaccurate data visualisations and inaccurate interpretations. As the data is measured annually and therefore could have inaccuracies, the analysed results from the data could be inaccurate.

The findings of this thesis shows that SPC can visualise data within a visualisation tool effectively, supporting the suggestions by Kindler and Martinson (2024). However, in highly controlled environments like nuclear power plants, the control lines and variation rules may require improvements. Kindler and Martinson (2024) highlighted the need for specific thresholds for control charts to yield more accurate results, a need also identified in this thesis. The control chart developed in this thesis illustrated a highly controlled process, suggesting that the control lines and rules might need adjustment to achieve true accuracy for the specific data. Creating ideal thresholds for particular processes would be a project in its own and is beyond the scope of this thesis. But the limitations observed in this study are similar to those identified in clinical care settings, as noted by Kindler and Martinson (2024). This similarity shows that while SPC and control charts have broad applicability, their implementation must be tailored to the specific context.

6.2.3 Power BI

The adoption of Power BI immediately benefitted the project by pre-emptively meeting two end user needs. Its integration with other Microsoft tools such as Power Point simplified the communication of visuals to external stakeholders. Additionally, the capability to automatically update from Excel documents made adding new data effortless. Power BI's design features and interactivity increased the understandability of the data presented, allowing for detailed analysis. The platform enables users to interact with data and dynamically alter visuals, expanding the range of analytical possibilities.

Power BI’s intuitive design allows beginners to easily make changes and adaptations to the tool without a comprehensive understanding of the functionalities. Initial program selection assessments were based on assumptions about various programs' learning curves. However, it became clear in retrospect that the basics of Power BI are relatively straightforward to master, suggesting that the initial difficulty rating could have been set lower. But gaining a deep understanding of the analysis and learning to program new functions will require users to advance their skills further.

The program faced certain limitations, particularly because it was deployed in a nuclear power plant setting. Due to safety concerns, the cloud services typically offered by Power BI were unavailable, restricting access to many functionalities and advanced analytic features. Consequently, users will need to program any required analyses using the built-in language, which significantly increased the learning curve for newcomers. This requirement also heightened the risk of miscalculations and errors, potentially leading to inaccurate data visualisations.

6.3 METHOD DISCUSSION

To effectively create a visualisation tool for a process in nuclear power plant, a structural approach was essential to ensure accurate results. A case study split into data collection and data analysis gave that general structure and was a perfect foundation. Collaborating with Vattenfall, particularly their Forsmark group, offered numerous insights into organisational processes and how their measurement and visualisation operations are conducted. By being directly integrated into the process, the author could gain firsthand experience and could much easily find the right information and the most fitting structure for interviews. But this direct integration did also influence the author to have somewhat of a subjective view of the analysis. This is because the direct contact gave an understanding of the process through the end users, which made the author feel like an end user themselves. This integration had both positive and negative effects as it increased the author’s understanding of end user needs but also introduced a greater degree of subjectivity into the results.

Another challenge from case studies was that cooperation with an organisation are highly time consuming and could potentially affect the scope of the project. In this case, the organisational cooperation had a late starting date which limited the time for the actual tool development and limited the potential features and research that comes with it. But the actual cooperation was time efficient and did not hinder the rest of the project as the contacts the author had were always quick to respond.

The interviews conducted used two different methodologies, unstructured and semi-structured interviews. The unstructured interviews were very effective in gaining insights into the specific needs that users might not think about from the start. The observational part of these interviews also set positive tone in the collaboration as it showed the employees of Vattenfall that the author had genuine interest in their work. Because of this integration into their processes, insights could be gained that could have otherwise been missed by solely relying on structured interviews. But the semi-structured interviews did also give a good amount of information. They could provide a broader perspective on the tool's requirements and what they are for. They could continue the relaxed setting the unstructured had started while ensuring that every interviewed employee answer similar questions, providing insights into the same key areas. Together, these methods complemented each other, resulting in both a general overview with the specific details of everyday contexts. With multiple methods of data collection, the data accuracy, and data validity increases.

The interviews were only conducted with six people from Vattenfall, limiting the objectivity of the results. However, the tool was developed for a specific process were very few people will be directly involved. Instead of finding every objective satisfactory requirement, the few people involved will have their specific needs addressed.

6.4 CONCLUSIONAL SUMMARY

The purpose of this thesis was to develop a visualisation tool using quality methods to improve data communication among stakeholders. The tool aimed to enhance data accessibility and understandability across the organisation. Hence, the thesis provides an analysis of how quality tools can effectively be used to develop a visualisation tool for nuclear power plants, highlighting the application of the Kano model, QFD, and SPC to meet end user needs and improve tool development outcomes.

RQ1: How can quality tools effectively identify and address the needs of end users in the development of a visualisation tool in a nuclear power plant?

The Kano model was used to categorise and prioritise end user needs effectively. It helped in understanding user requirements and created a structured approach and prioritisation, though the categorisation process showed some subjectivity and overlap in satisfaction levels. Categorised needs could overlap each other, needs correlating ease of use were found to be both a must-be and one-dimensional.

The QFD house of quality tool translated end user needs, from the Kano model, into actionable features. It identified connections between needs and features, however QFD generally fits better with physical products and was limited in addressing software functionalities. If used only as a supporting tool, then most limitations could be avoided.

RQ2: How can a quality-based visualisation tool improve the visualisation process and increase the understandability of the current data in a nuclear power plant?

SPC was used to enhance the data analysis, specifically with control diagrams that were requested by end users. The integration of control diagrams enhanced the understandability of data in the long-term. In specific cases, SPC could need adapted thresholds to ensure accurate data analysis.

The thesis further discusses the effectiveness of effective visualisation theory and the program Power BI on both the development process and the visualisation process at Vattenfall. Implying how the resulting tool affects future understandability and visual efficiency. Effective visualisations were proven to greatly improve the understandability of the tool and could enhance the overall results.

6.5 RECOMMENDATIONS FOR FUTURE RESEARCH

Building upon the findings and experiences from this thesis, several areas for future research can be explored to further increase the application and adaptability of quality tools in specialised areas. The following recommendations aim to address the gaps identified during this study while adding to the overall continued improvement efforts of quality management.

Kano model categorisation

The categories used in the kano model does not perfectly match the end user needs satisfaction expectations. Future research could explore methods to calculate a more accurate satisfaction level so that user needs can be represented correctly. Researchers could also potentially employ artificial intelligence to eliminate subjectivity in the categorisation. This would lead to a more universally adapted version of the Kano model which would improve the industry's understanding of customer needs and expectations.

Effective visualisation

As effective visualisation theory increasingly integrates with quality management, future research should investigate the potential to update quality tools by incorporating effective visualisation techniques. This could lead to improved data-driven decision-making within quality projects, raising the standards of quality.

Project continuance

The thesis resulted in a tool designed to increase the efficiency of the visualisation process at Vattenfall. However, the tool was never tested in practice. If the tool were tested, new results and improvement areas could potentially reveal themselves, further improving visualisation efficiency. Future research could also explore the potential of expanding the tool's application to other visualisation processes, both internally at Forsmark and at other power plants. This expansion could provide even more valuable insights into the tool's adaptability and effectiveness across different settings.

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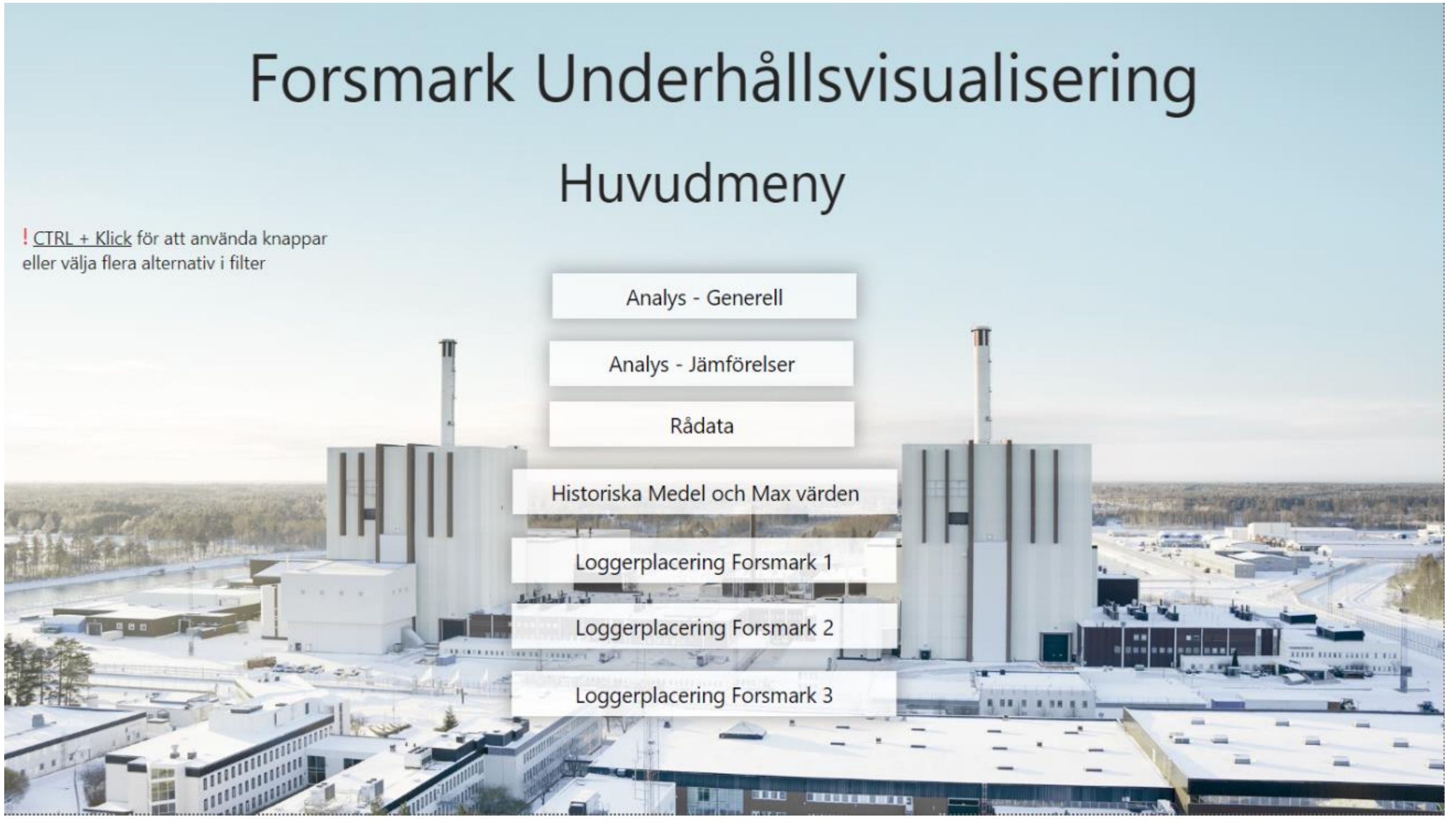
APPENDIX A

VISUALISATION TOOL'S MAIN PAGE. Translation:
Forsmark Underhållsvisualisering = Forsmark Maintenance visualisation, *Huvudmeny* = Main menu, *Analys – Generell* = Analysis – General, *Analys – jämförelse* = Analysis – Comparison, *Rådata* = Raw data, *Historiska medel och max värden* = Historical averages and max values, Loggerplacering Forsmark = Node placement Forsmark, *CTRL + Klick för att använda knappar eller välja flera alternativ i filter* = CTRL + Click to use buttons or chose multiple options in filters.



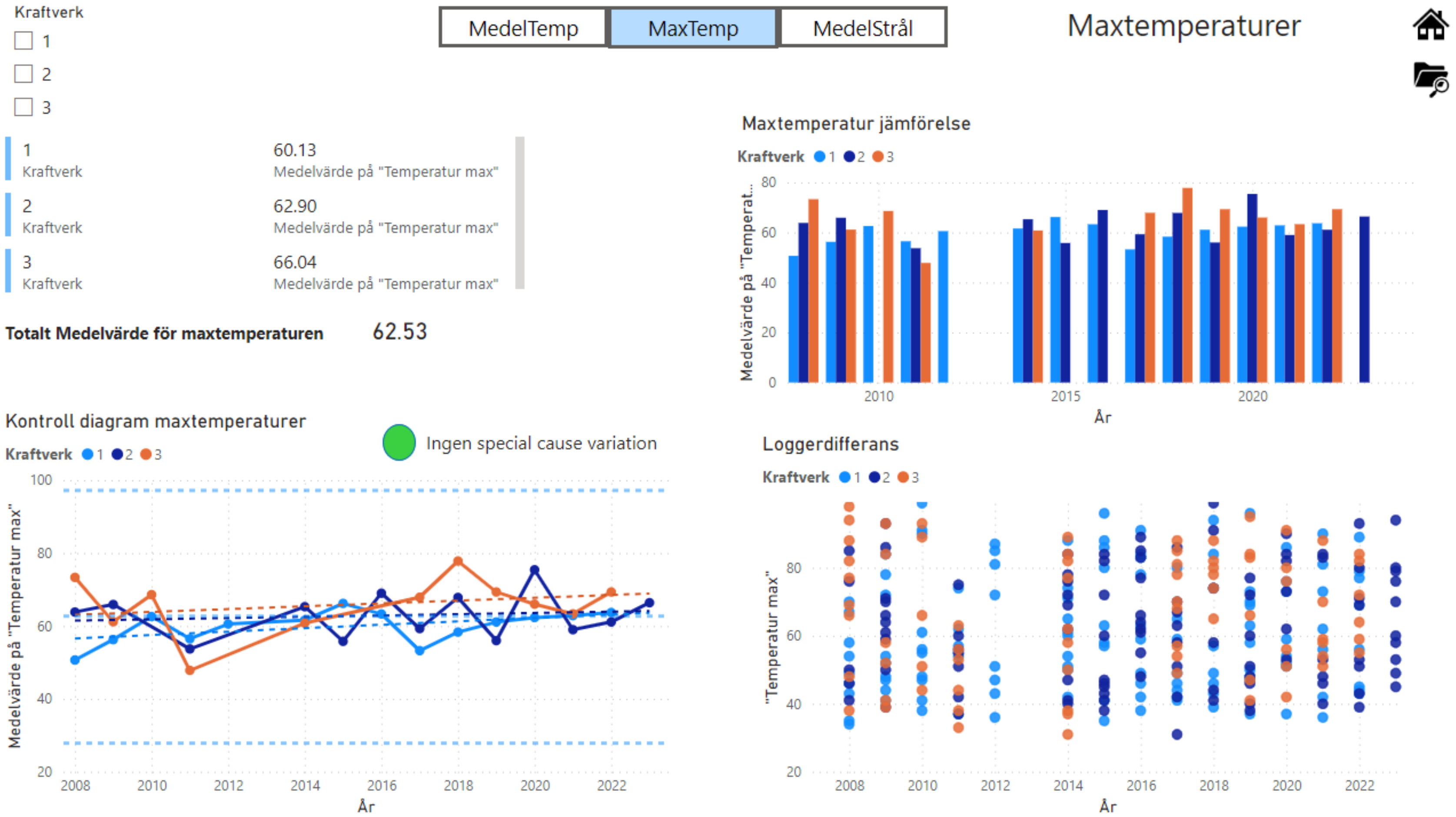
APPENDIX B

ANALYSIS GENERAL PAGE FOR AVERAGE TEMPERATURE VALUES.

Translation: *Kraftverk* = Power plant, *Medelvärde* = average, Medeltemperatur = average temperature, *medelvärdejämförelse* = average comparisons, *Kontroll diagram av medelvärde* = Control diagram of averages, *Ingen special cause variation* = No special cause variation, *Loggerdifferans* = Node difference, *År* = year.

Appendix C

Analysis general page for max temperature values. Translation:
Kraftverk = Power plant, *Medelvärde* = average, Maxtemperatur = Max temperature, Maxtemperatur = radiation comparisons, *Kontroll diagram maxtemperaturer* = Control diagram max temperature, *Ingen special cause variation* = No special cause variation, *Loggerdifferans* = Node difference, *År* = year.



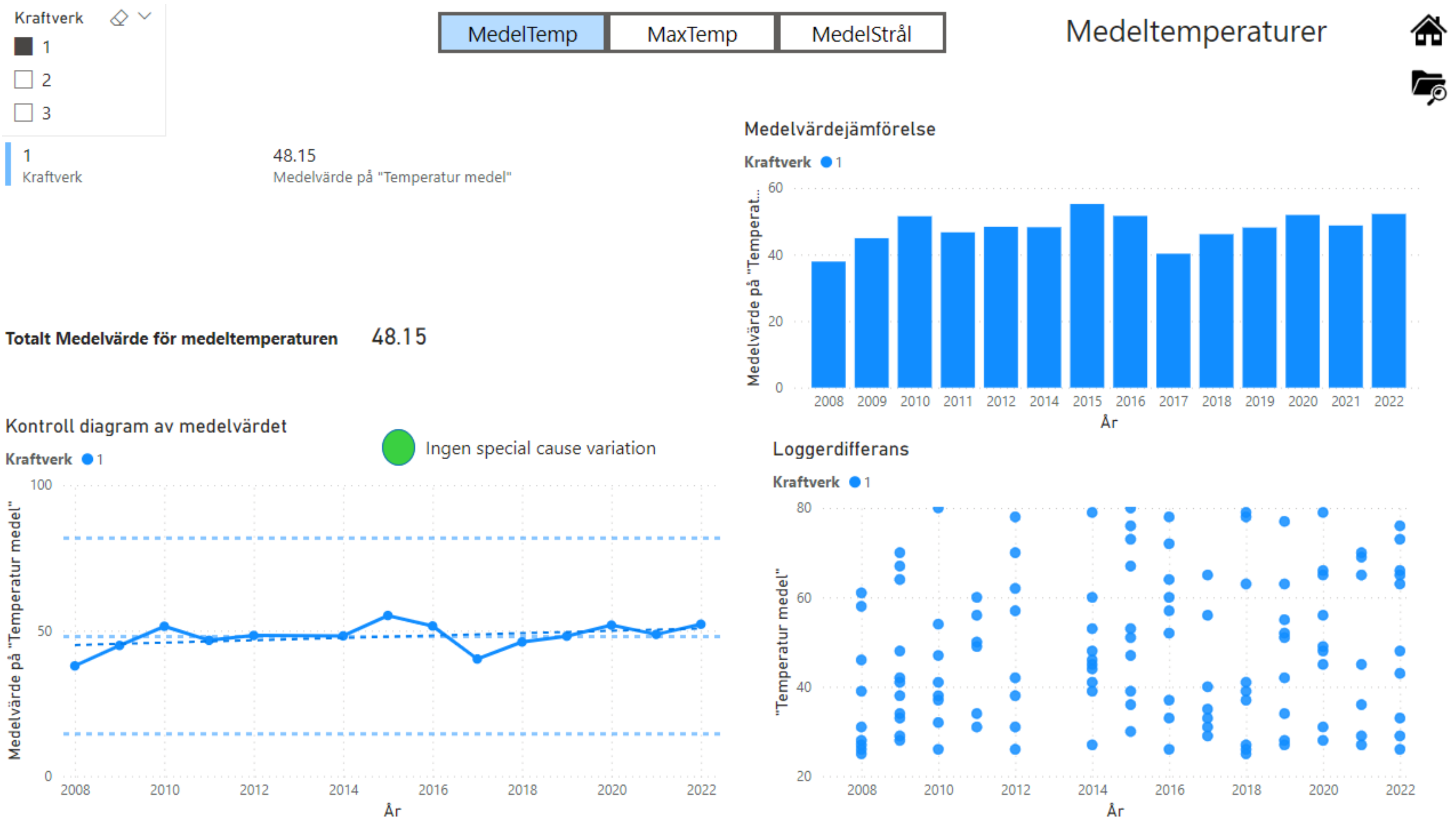
APPENDIX D

ANALYSIS GENERAL PAGE FOR RADIATION VALUES. Translation:

Kraftverk = Power plant, *Medelvärde* = average, Medelstrålning = average radiation, *strålningsjämförelse* = radiation comparisons, *Kontroll diagram av strålning* = Control diagram of radiation, *Ingen special cause variation* = No special cause variation, *Loggerdifferans* = Node difference, *År* = year.

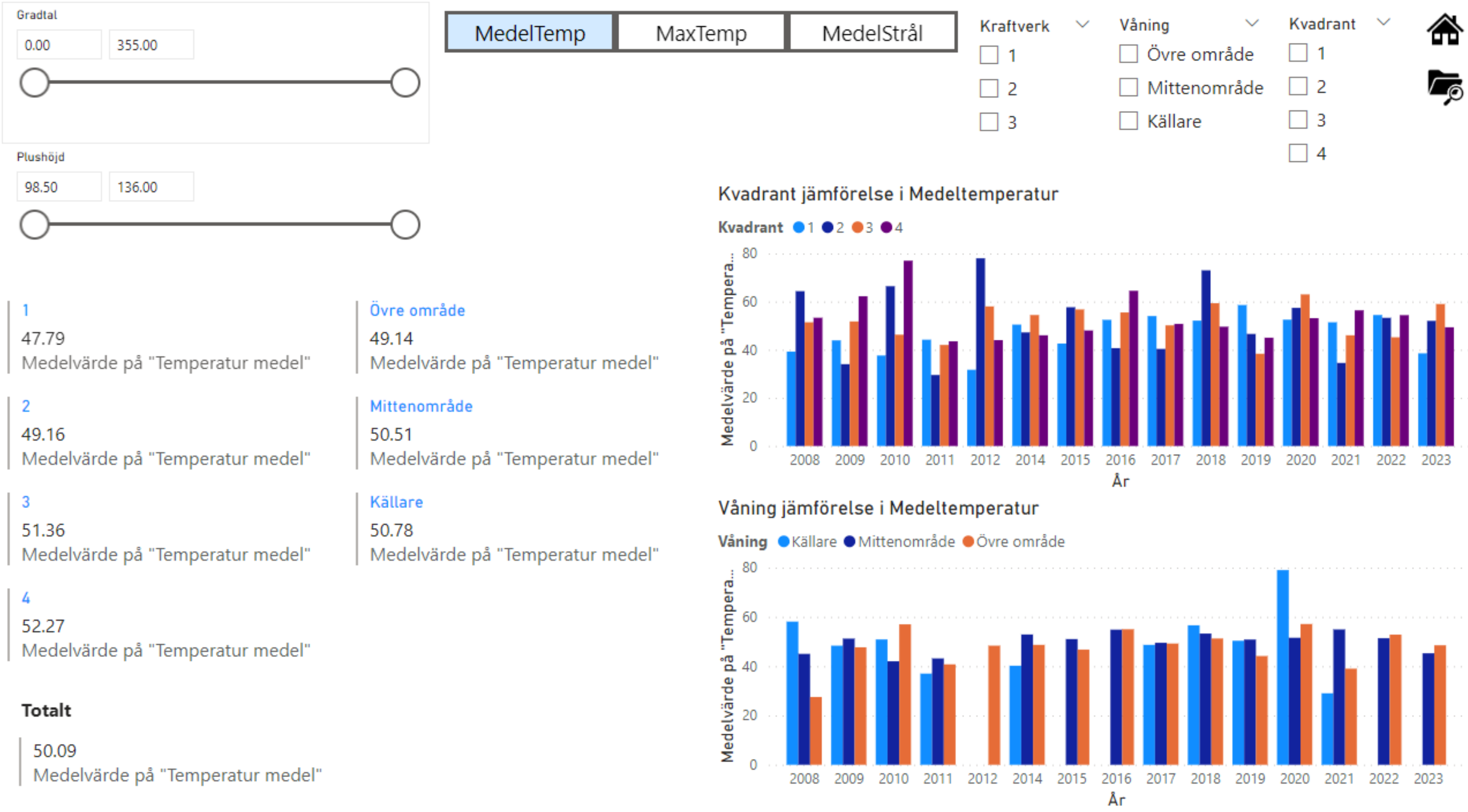
APPENDIX E

ANALYSIS GENERAL PAGE FOR AVERAGE TEMPERATURE VALUES WHERE ONLY ONE REACTOR IS SELECTED. Translation: *Kraftverk* = Power plant, *Medelvärde* = average, Medeltemperatur = average temperature, *medelvärdejämförelse* = average comparisons, *Kontroll diagram av medelvärde* = Control diagram of averages, *Ingen special cause variation* = No special cause variation, *Loggerdifferans* = Node difference, *År* = year.



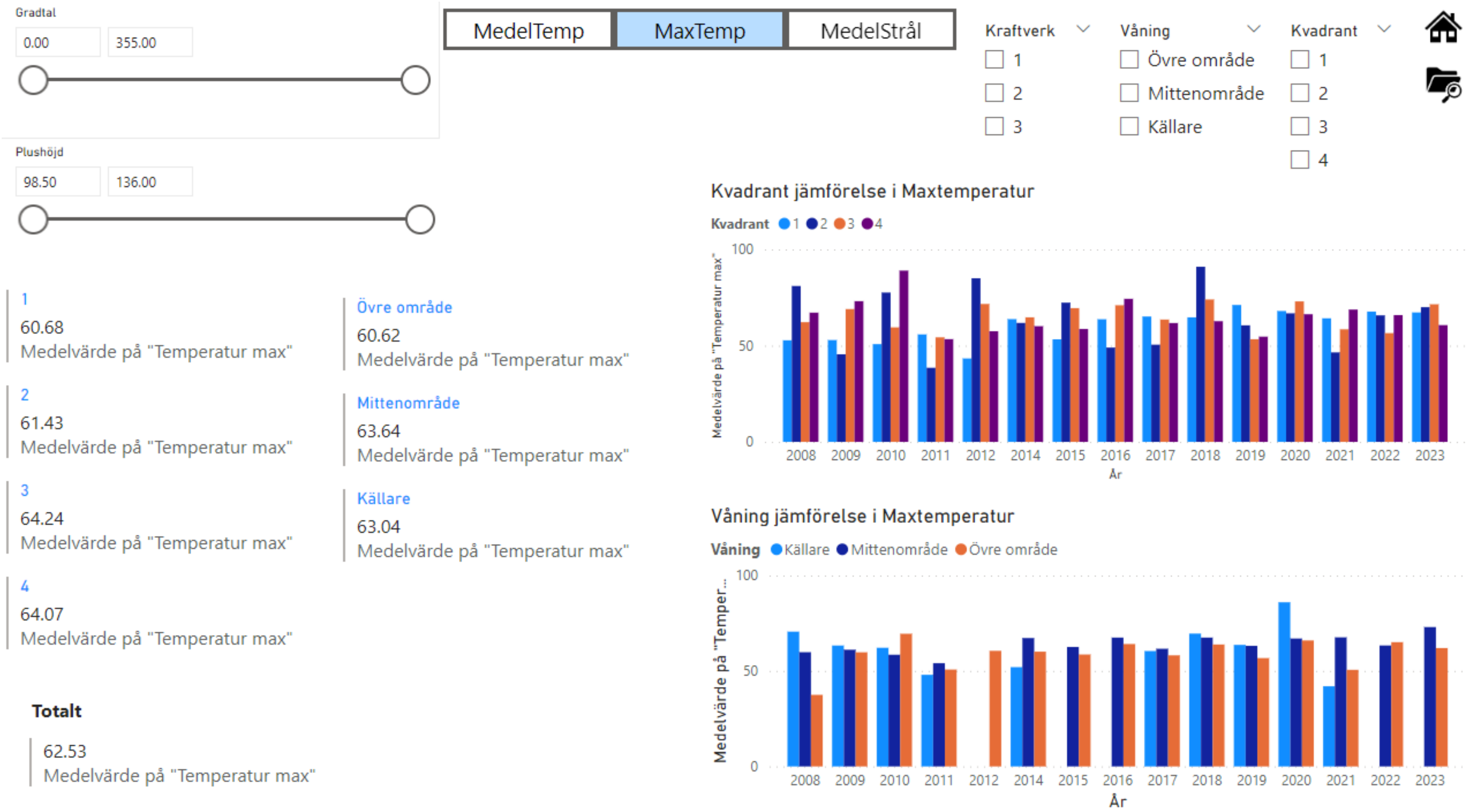
APPENDIX F

ANALYSIS COMPARISON PAGE FOR AVERAGE TEMPERATURE. Translation:
Gradtal = Degree, *Plushöjd* = Height, *Kraftverk* = Power plant, *Våning* = Floor level, *Kvadrant* = Quadrant, *Övre område* = Upper area, *Mittenområde* = Middle area, *Källare* = Basement, *Jämförelse* = comparison, *Medeltemperatur* = average temperature, *År* = Year.



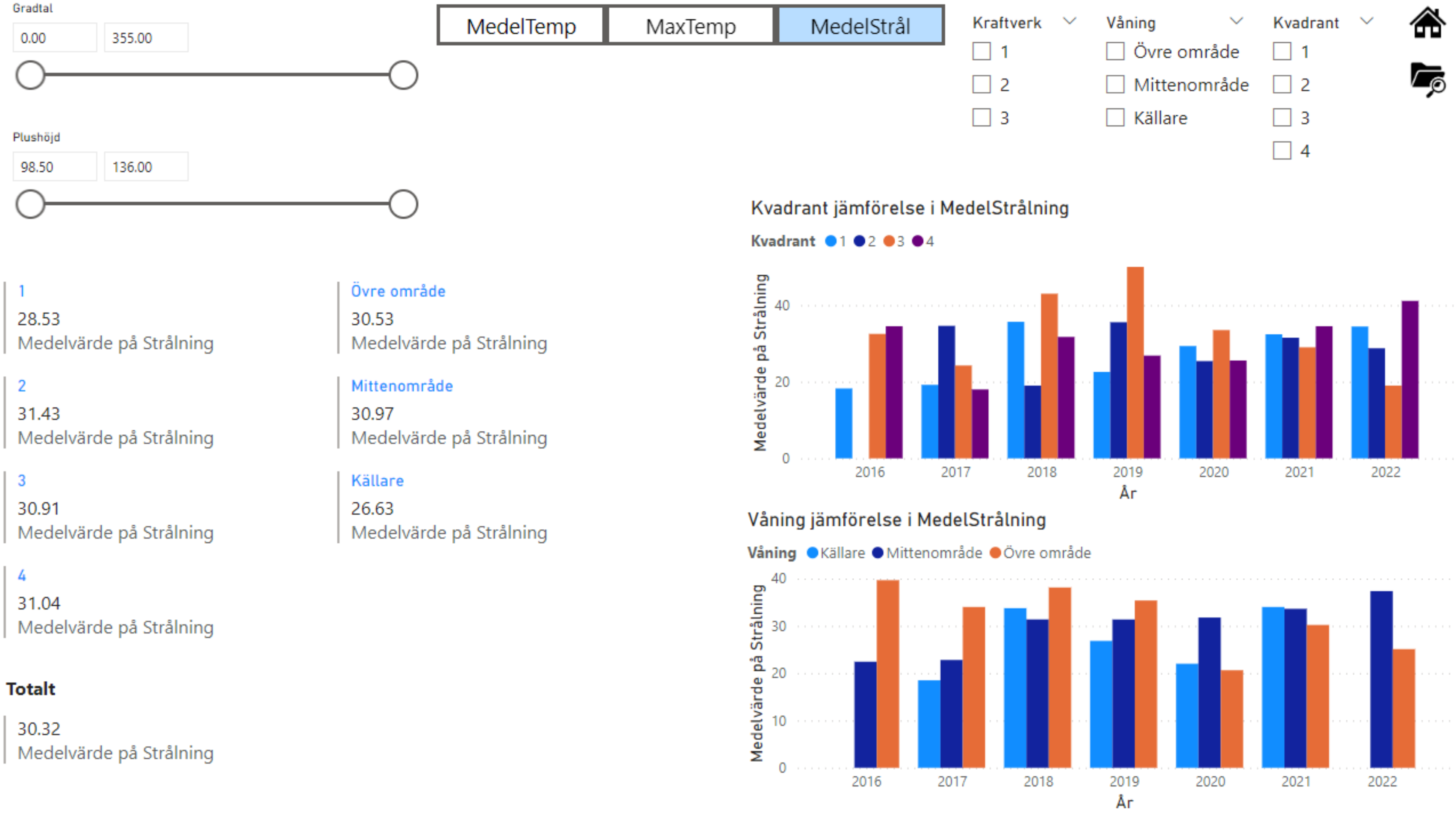
APPENDIX G

ANALYSIS COMPARISON PAGE FOR MAX TEMPERATURE. Translation:
Gradtal = Degree, *Plushöjd* = Height, *Kraftverk* = Power plant, *Våning* = Floor level, *Kvadrant* = Quadrant, *Övre område* = Upper area, *Mittenområde* = Middle area, *Källare* = Basement, *Jämförelse* = comparison, *Medeltemperatur* = average temperature, *År* = Year.



APPENDIX H

ANALYSIS COMPARISON PAGE FOR RADIATION. Translation:
Gradtal = Degree, *Plushöjd* = Height, *Kraftverk* = Power plant, *Våning* = Floor level, *Kvadrant* = Quadrant, *Övre område* = Upper area, *Mittenområde* = Middle area, *Källare* = Basement, *Jämförelse* = comparison, *Medeltemperatur* = average temperature, *År* = Year.

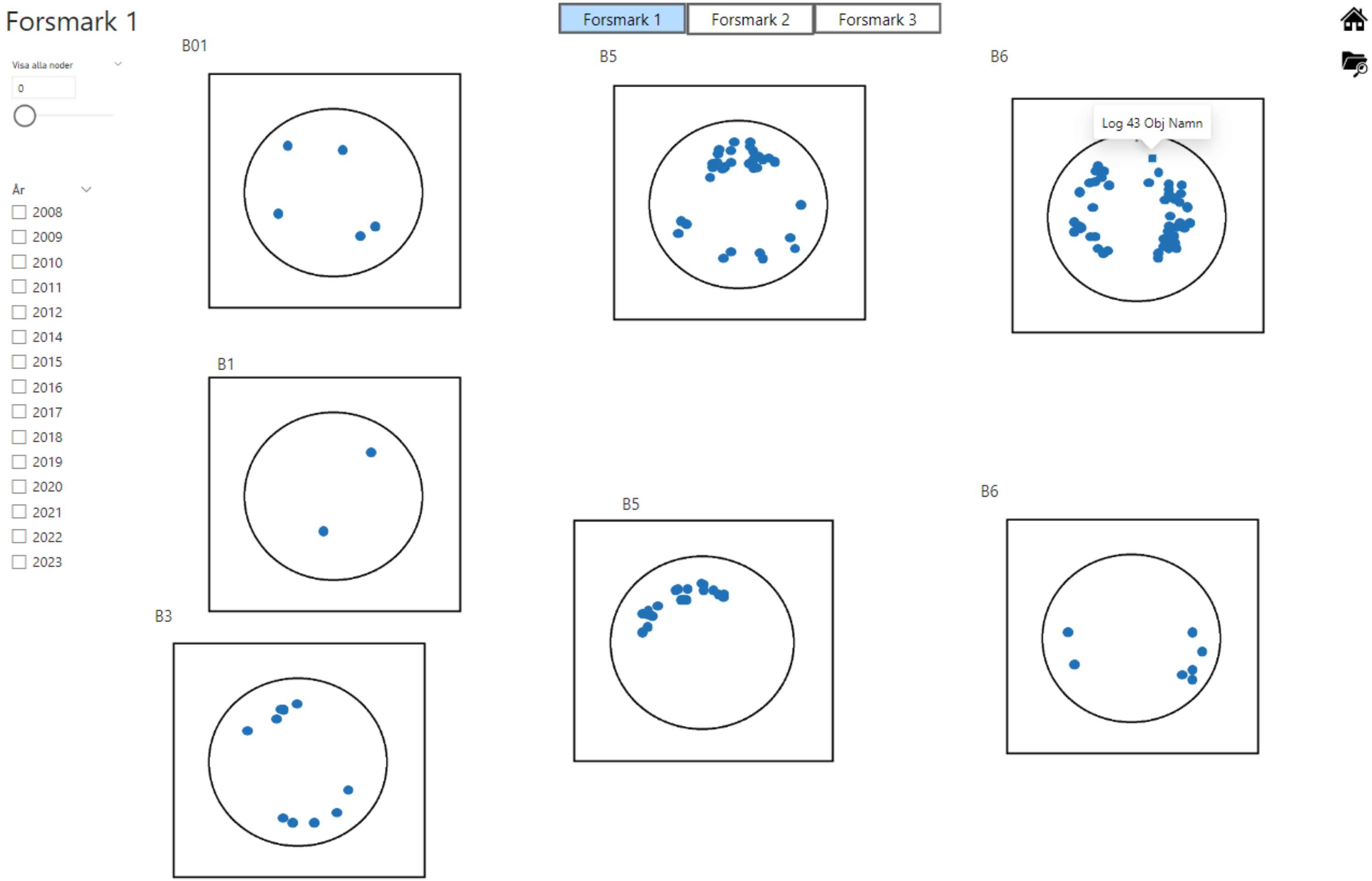


APPENDIX I

HISTORIC MEAN AND MAX VALUES PAGE. Translation:
Gradtal = Degree, *Plushöjd* = Height, *Kraftverk* = Power plant, *Våning* = Floor level, *Kvadrant* = Quadrant, *Övre område* = Upper area, *Mittenområde* = Middle area, *Källare* = Basement, *Medelvärde* = Average, *Medelvärden på Medel- och Maxtemperaturer / Strålning* = Averages of average and max temperature/radiation, *År* = Year.

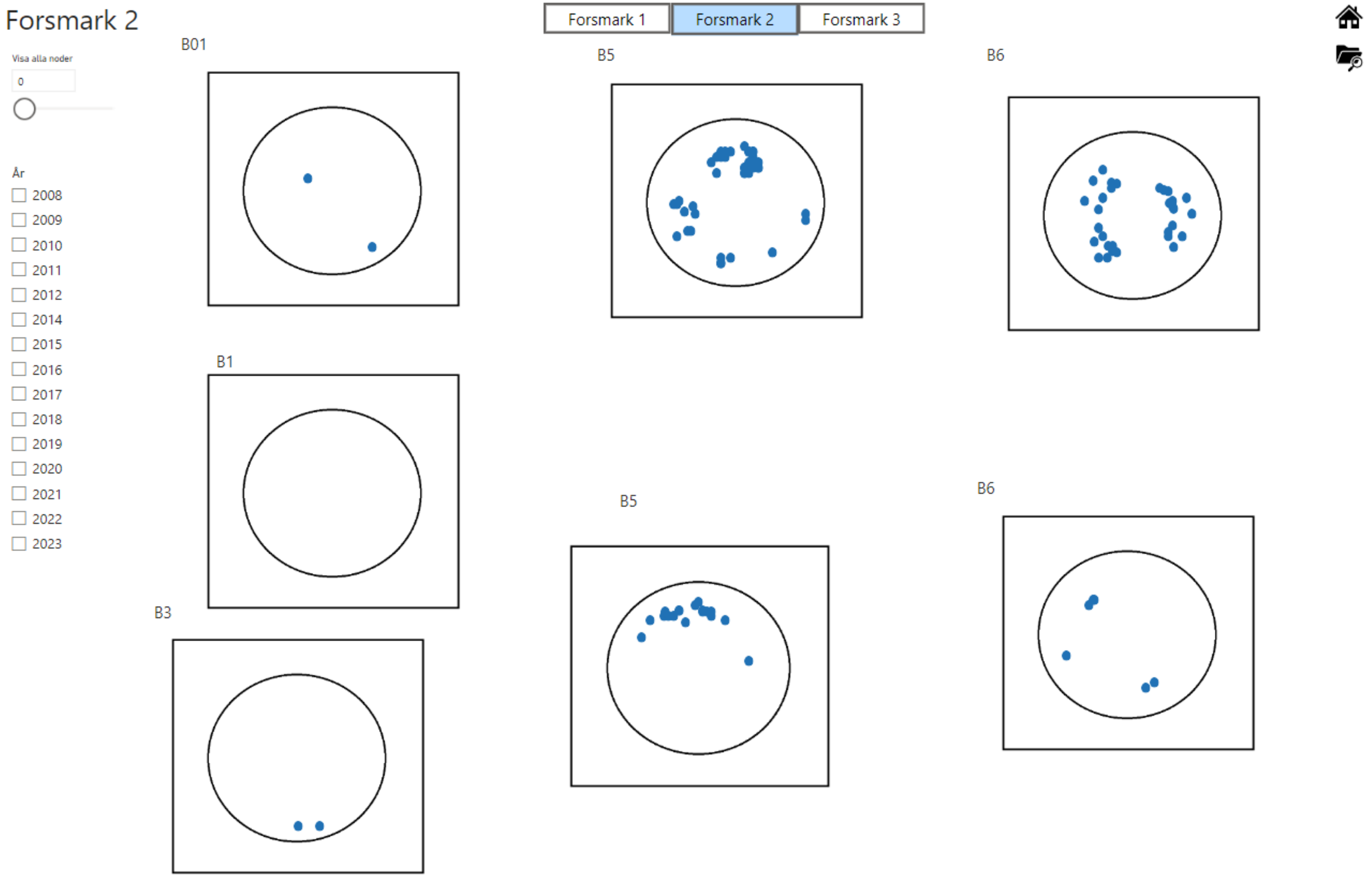
APPENDIX J

NODE PLACEMENT PAGE FOR REACTOR ONE OR “FORSMARK 1”. Translation: *Visa alla noder* = Show all nodes, *År* = year, *Namn* = Name.



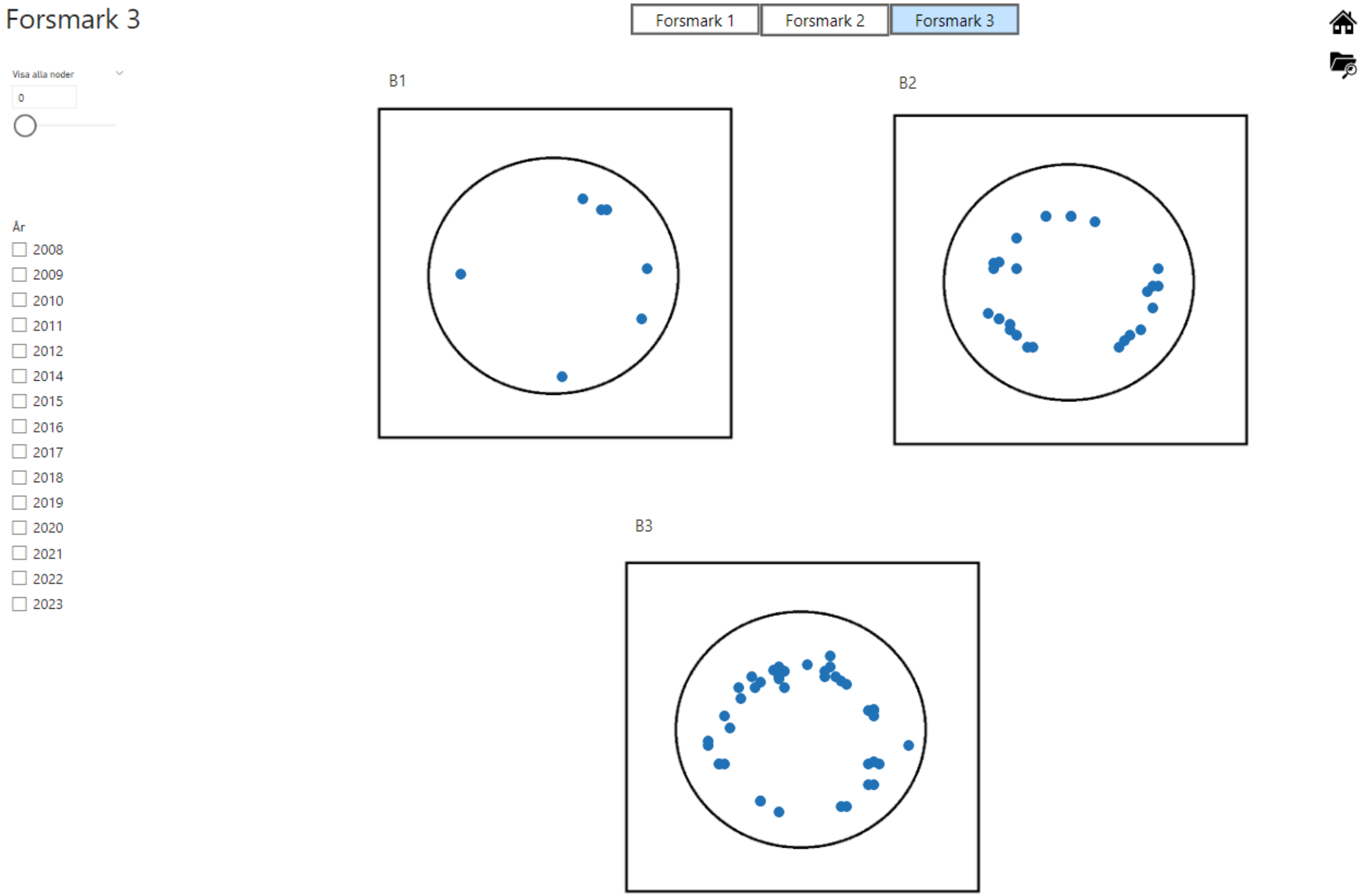
APPENDIX K

NODE PLACEMENT PAGE FOR REACTOR TWO OR "FORSMARK 2". Translation: *Visa alla noder* = Show all nodes, *År* = year, *Namn* = Name.



APPENDIX L

NODE PLACEMENT PAGE FOR REACTOR THREE OR "FORSMARK 3". Translation: *Visa alla noder* = Show all nodes, *År* = year, *Namn* = Name.



APPENDIX M

RAW DATA PAGE. Translations:
År = year, *Kraftverk* = Power plant, *Namn på objekt* = Name of object, *Plushöjd* = Height, *Gradtal* = Degree, *Temperatur medel* = Temperature average, *Temperatur* max = Temperature max, *Strålning* = Radiation

År
- ☐ 2008
- ☐ 2009
- ☐ 2010
- ☐ 2011
- ☐ 2012
- ☐ 2014
- ☐ 2015
- ☐ 2016
- ☐ 2017
- ☐ 2018
- ☐ 2019
- ■ 2020
- ☐ 2021
- ☐ 2022

Kraftverk
- ■ 1
- ☐ 2
- ☐ 3

Namn på objekt (Loggernummer)	Plushöjd	Gradtal	Temperatur medel	Temperatur max	Strålning
13	134.00	120.00	66.00	76.00	41.00
17	124.00	348.00	79.00	86.00	22.00
26	128.50	30.00	48.00	59.00	17.00
41	124.50	348.00	31.00	51.00	51.00
42	134.00	100.00	49.00	54.00	29.00
50	134.00	260.00	65.00	73.00	7.00
63	131.00	110.00	45.00	52.00	48.00
65	124.50	348.00	56.00	73.00	36.00
67	134.00	310.00	28.00	37.00	23.00

APPENDIX N

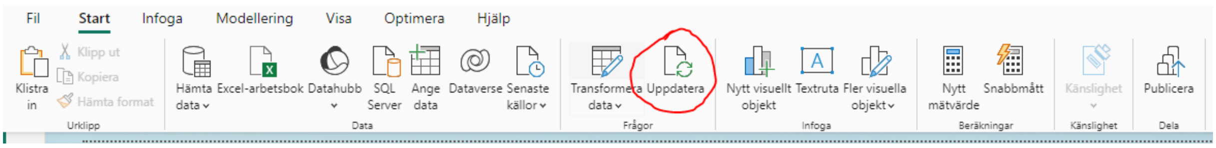
USER GUIDE FOR UPDATING DATA AND NODES IN POWER BI

Written in Swedish (No translation provided).

Manual för fortsatt uppdatering och utveckling av visualiseringsverktyg i Power BI

Excel-filen och datauppdatering i Power BI

- För det första gäller det att uppdatera Excel-filen med data, då kategorierna är kopplade till Power BI så är det bra om de befintliga kategorierna fylls på och inte förändras.
    - Om nya kategorier skall läggas till är det bara att skriva in dem i en tom kolumnrad bredvid befintliga så kommer de läggas till i tabellen automatiskt.
- Efter detta, spara Excel-filen och öppna Power BI verktyget.
- I Power BI – i ”START” finns en symbol som heter ”Uppdatera” – Efter att man klickar på den kommer all data uppdateras och alla diagram kommer anpassa sig efter den nya datan. Se bild:



Lägg in nya noder i Loggerplaceringen

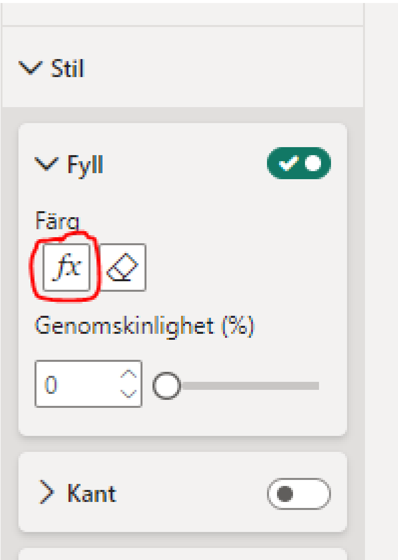
För att addera nya loggerplaceringar kommer inte bara noder behövas läggas till utan även programmeras, men oroa inte för det är redan gjort!

Börja med att kopiera följande kod (Den finns även att hitta under tidigare års koder/mätvärden som ligger i högerspalten under data):

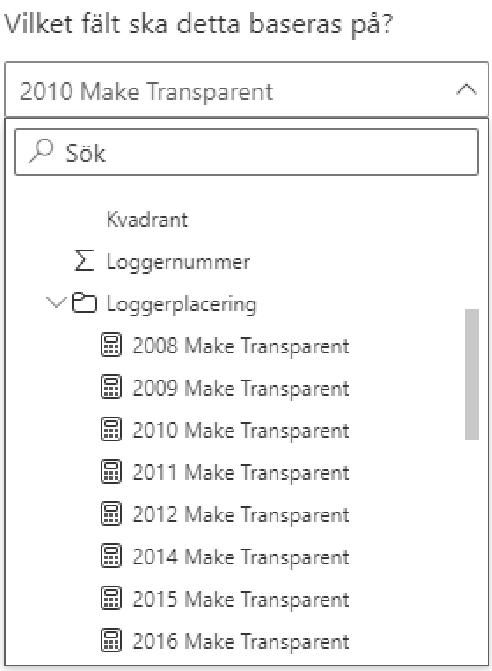
```
20xx Make Transparent =

    IF(
      OR(20xx IN ALLSELECTED(Data[År]), SELECTEDVALUE(Nod[Visa])=1), -- kollar om valt år är det året som vi vill ha
      "#2071B5", -- färgen punkten ska ha när den är vald
      "#FFFFFF00" -- gör punkten transparant när den inte är vald
    )
```

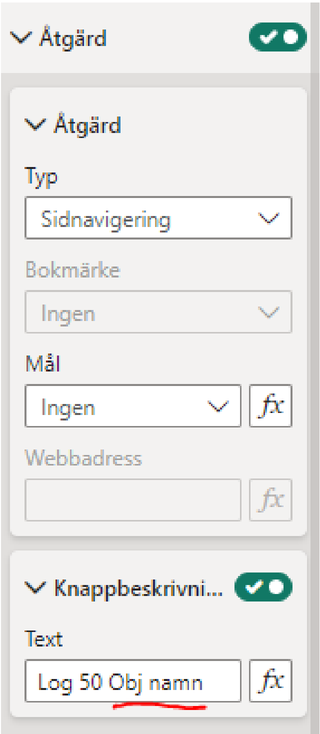
- I startmenyn, klicka på miniräknaren som heter ”Nytt mätvärde” – kopiera in koden och ändra de **två xx (se gulmarkering ovan)** i årtalen för det år som du vill ha. Klicka enter.
- Gå nu till ett tidigare år och kopiera en nod, klistra in noden och flytta den så att du har en nod redo att placeras.
    - **Varning**: Se till att den inte ligger i bilderna då det är lätt att den blandas in med de andra noderna som ligger där, även tidigare år kan råkas klickas på
- Ta den nya noden och klicka på den, vid högersidan under ”Format” finner du en kategori som heter ”Stil”. Under denna kategori finns en ”Fyll” kategori som under sig har en symbol på ”fx” – klicka på den, se bild.



- Under frågan ”Vilket fält ska detta baseras på?” väljer du den kod du nyss lade till, se bild nedan, den heter ”20xx Make Transparent” med xx utbytt till det nya året. Klicka ok (noden bör försvinna)



- Klicka nu på det nya året i filtret på vänster sida, noden bör nu dyka upp. Kopiera denna nod för varje nod du skall lägga till.
    - **OCH** – för varje ny nod behövs en ny beskrivning, klicka på noden – sedan åtgärd i högerspalten – under knappbeskrivning skriver du logg nummer och objekt namn, då kommer rätt visas när man hovrar över noden.



- Placera noderna på rätt plats, behövs gradtal och höjd kan du hitta det på ”Hitta data” sidan (Klicka in rätt kraftverk och år för att se aktiva noder)

Addera ny data i graf (Om det behövs/finns nya kategorier som mäts)

- Skall nya grafer eller sidor läggas till kan man enkelt kopiera eller duplicera redan befintliga så behålls format, det här fungerar liknande för alla Power BI's funktioner såsom knappar eller filter med mera.
- Ska ny data adderas i en graf som redan har data i sig, eller om någon data skall bytas ut, så gör det genom att klicka på grafen och sedan dra relevant data från högerspalten lägst till höger till den bredvid under "Y-axel" eller "X-axel". Se bild