Environmental Key Performance Indicator with relation to quality costs and their visualization

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Abstract

With the emergence of the Corporate Sustainability Reporting Directive, companies became obliged to disclose their sustainability information in the same manner they did with their financial data. Moreover, social responsibility steadily gains more effect on purchasing decisions. Hence, different types of enterprises are interested in finding ways to communicate their sustainability situation and obtain an advantage in this sphere.

The commissioner of this thesis is Meconet Oy, a manufacturing company based in the European Union. Its concern is to measure the spending on EU cap-and-trade emission permits related to quality claims. It is known that whenever a quality claim is received by Meconet, the entire batch claimed to be faulty is revoked, incurring greenhouse gas emissions due to transportation. If any number of items proves to be actually defective, replacement units are produced, incurring emissions due to rework. By being capable of tracking the costs related to these GHG sources, Meconet will enable itself to prepare sustainability reports and motivate its personnel to prevent quality issues.

Literature study, quantitative and qualitative methods were merged to prepare the Key Performance Indicator for this purpose. Mathematical formulas based on variable indexes were proposed to compute the mass emitted. A number of chart types were selected to motivate Meconet employees through visualization. Recommendations were given in order to assist the company with KPI implementation.

By utilizing the knowledge expounded, Meconet will be able to enact a system that would measure environmental quality costs and possibly engage workers to reduce them.

Keywords/tags (subjects)

Transportation, rework, quality, sustainability, emissions, metrics.

Miscellaneous (Confidential information)

Appendices 2 and 3 include confidential information, which are hidden from the public thesis. The basis for secrecy is section 24(17) of the Act on the Openness of Government Activities (621/1999), a company's business or trade secret. The period of secrecy is five (5) years, the secrecy will end on 18 May 2028.

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1 Introduction

The modern way of life is highly dependent on the industry. Being able to mass-produce goods, including technology-intensive ones, has strongly affected the world as we see it today. However, the power of change also implies the corresponding responsibility for industrial companies. Life is changing once again with the switch to renewable energy and circular economy, and society is in its own right to demand adaptation to the new conditions from production enterprises.

One such shift is climate change. Industrial processes produce greenhouse gases accounting for 6,1% of total emissions (Ge et al., 2020). This number does not include energy consumed during the work in the factories. This issue has recently been of concern for civil society and international organizations such as OECD (OECD Environment Directorate, 2003). For instance, the European Union issued the Corporate Sustainability Reporting Directive in the year 2022, which implies that almost all listed companies are obliged to report their sustainability data in the same manner and with the same level of responsibility they were required to do with the financial information. (The European Parliament & The Council of The European Union, 2022) The fact that many manufacturing businesses will soon fall under the Corporate Sustainability Reporting Directive regulations should be of no surprise. Among other requirements, a CSRD-abiding sustainability report will need to include applicable Key Performance Indicators. (The European Parliament & The Council of The European Union, 2022) Hence, the desire of the thesis commissioner to establish a theoretical basis for them is also fathomable.

This study involves a case company that pays attention to the sustainability regulations to be imposed. The thesis aims to assist in adapting its business cycles to the new legal environment. In addition, the end result drives the case company towards the target of improving employee empowerment and personnel's environmental awareness.

The background of the topic is as such. The case company's production process is an imperfect one, as well as its quality assurance measures. As a consequence, cases of detection and, more importantly, revoking defective batches occur periodically. Processes related to handling quality claims for such batches cause greenhouse gas emissions, thus incurring costs for the manufacturer. Methods of demonstrating the process of mitigating these expenditures are discussed in this paper.

1.1 Case company profile

1.1.1 General information

The company which commissioned this thesis is the manufacturing enterprise called Meconet Oy. It started operating in 1896, specializing in the production of springs, wire forms, and deep drawing parts, as well as assembly and delivery management. Production is based solely in the European Union: as of 2022, Meconet owns factories in Vantaa, Äänekoski, Pihtipudas, and Tallinn. (Meconet Oy, 2022)

The product range includes, in addition to standard compression, extension, torsion, and flat springs, certain self-designed wire forms. (Sutinen, n.d.) There is no pre-defined product list for stamped and deep-drawn products: the design is tailored to a specific need by Meconet engineers or the customer. In addition to designing, other services are available, including but not limited to (Meconet Oy, n.d.):

- Production Part Approval Process
- Measurement of machining results and 3D laser scanning
- Product manufacturability analyses and simulations
- Manufacturing method optimization
- Tool design
- Prototyping
- Outsourcing projects

In 2022, the enterprise employed around 330 people (Aatola, personal communication, April 20, 2023). It states that the batches of stamped products can reach several million in volume, with ten thousand of them processed concurrently (Ryhänen, n.d.). Such production volumes impose a certain environmental responsibility, even excluding any other matters.

In terms of technologies used, the multi-side pressing method is the most advanced one. Springs and stamped forms are manufactured in this manner by Meconet (Ryhänen, n.d.). Servo pressing, pre-stressing, and shot peening are several other production methods implemented by the company (Meconet Oy, n.d.). The company is willing to combine the LEAN philosophy with all the abovementioned methods to ensure quality and continuous improvement. As for the environmental aspects, Meconet was awarded a Silver sustainability rating by Ecovadis (Meconet Oy, n.d.).

The commissioning of this thesis work also indicates Meconet's willingness to achieve better results instead of keeping the status quo.

1.2 Emission Scopes as a key concept

Greenhouse gases are generated by different sources, which are subject to classification. Developed by World Economic Council for Sustainable Development and World Resources Institute (World Economic Council for Sustainable Development & World Resource Institute, 2004), the concept of emission Scopes will be used throughout the paper.

Scope 1 emissions are defined as the greenhouse gases produced due to the company's own energy production, owned vehicles' fuel combustion, and other manipulations with the company's direct property. Scope 2 emissions are caused by greenhouse gas generation activities aimed to produce the energy the enterprise would purchase later. Scope 3 emissions, in turn, are represented by the carbon dioxide and its equivalent generated up and down the value chain. In other words, each greenhouse gas generating process within the product's lifecycle, from raw materials extraction to scrapping, will contribute to Scope 3 emissions regardless of the actor unless the process already belongs to Scope 1 or Scope 2. Below is the chart by Meconet explaining the core idea.

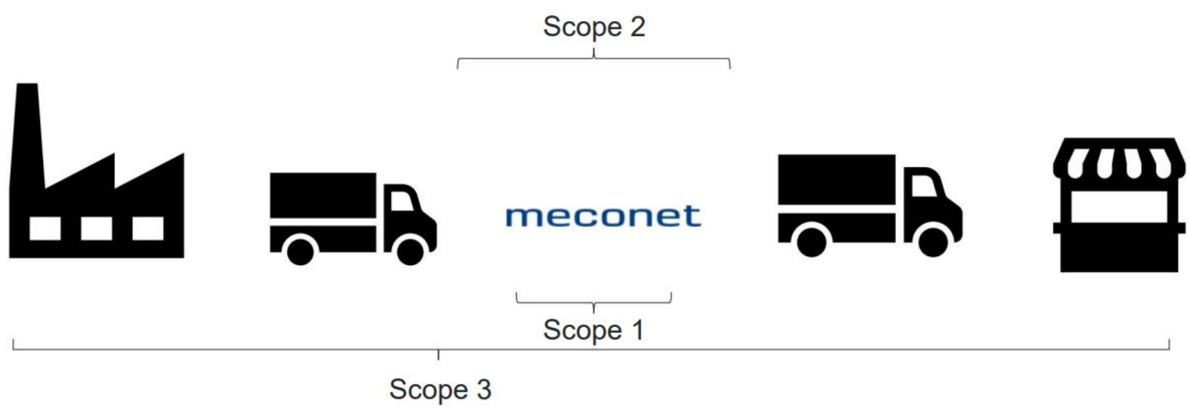

Figure 1. Schematics of Meconet emission scopes. (Meconet Oy, 2022)

1.3 Research questions

The result of this study is in the form of a formula with different company's performance characteristics as arguments and the final KPI value as a function. Moreover, specific recommendations concerning visualization and practical implementation have been given. As a matter of fact, it answers the following three questions:

i. How can Meconet numerically reflect its progress in achieving carbon neutrality in terms of quality?
ii. How to represent this reflection in a simple and understandable form?
iii. How will the resulting Key Performance Indicator benefit both Meconet's employee empowerment strategy and its abidance by the CSRD norms?

2 Methodology

The work in question is conducted with the use of a mixed research method. The literature study component is present as a compilation of already existing studies and is the thesis' integral part (Snyder, 2019). The qualitative component is represented by the analysis of the data given within interviews (Pathak et al., 2013). The quantitative component is due to the concept of a KPI being numerical by its nature and a large amount of Meconet data to be analyzed and translated into hypothetic form (Philips, 2000). The latter method is widely used in business due to its practice orientation and relatively simple result presentation. (Thakur, 2021)

2.1 Limitations

This study focuses on a single enterprise, as the answers to the abovementioned research questions are tailored to meet the needs of a particular company at a particular moment. The optimal solution may differ if another company is taken or Meconet's processes or supply chains are modified. Introducing new types of goods to manufacture may result in the need to change the KPI and its representation accordingly. Moreover, one must remember that the CSRD guidelines and other environmental requirements are subject to change as the years pass.

The focus of this study is not the general improvement of production. The thesis observes only the environmental aspects of manufacturing. Scope 3 emissions and emissions from sorting activities also do not fall under the scope of this work.

2.2 Study process

In the preparation of the thesis work, the following steps were taken:

2.2.1 Literary review.

The research already conducted by various scholars is a substantial part of this thesis. With other enterprises' real-life experience and theoretical fundament, the work on the KPI can be significantly streamlined. In addition, paying respect to the other researchers' work is what generous scientific practice requires.

2.2.2 Data overview.

The collection of information is not limited to the study search, however. Meconet and other enterprises' available statistics serve as the model inputs for the KPI end formula. The question this step poses is, "What is known about Meconet, and what do other scholars think about emissions caused by quality issues?"
The data collection methods used in this paper belong to both qualitative and quantitative groups. Employee interviews and international article searches represent the former, while the latter includes searching for numerical information in Meconet documentation.

2.2.3 Data analysis.

The information collected in the previous step is then handled to produce possible solutions for Meconet's case. The essential parts are excerpted from the scientific works, and the most illustrative statistical entries are picked. In short, this part answers the "what can be done?" question.

2.2.4 Mathematical formulation

In this step, the data and the theoretical basis are compiled to derive the solution that is believed to be the optimal one. The final formula for the KPI is given, and the choice of variables and mathematical tools to form it is justified. Overall, the step answers the question, "What should be done?"

2.2.5 Delivery formulation

Due to the awareness and motivation being in the spotlight in this study, the ways to present the KPI value and the progress towards its improvement are of particular importance. This step utilizes the literature and the author's ideas to understand what form of visual representation will answer the Meconet needs most comprehendingly. The question answered is the same as in the previous step.

2.2.6 Conclusion

The results are to be summarized in a convenient way, which is done in this step so that the commissioner would be able to acquire general comprehension of what the work suggests. Furthermore, significance discussion, reliability analysis, and recommendations for further improvement are outlined in this step.

3 Literature review

Galchenko (2022) states that two primary sources of greenhouse gas emissions exist for a manufacturing company such as Meconet: transportation and manufacturing, and the former is responsible for at least 94% of CO_2 produced. Then, it would be reasonable to base the formula on the abovementioned two kinds of costs. A further look inside both aspects is needed to obtain a strong foundation.

3.1 Emissions cost for transportation in literature

Fundamental cost type division from the scholars' viewpoint

As a starting point, Sarkar et al. (2015) believe that shipment emission costs can be divided into two categories: fixed costs [$/shipment] and variable costs [$/unit transported]. As a consequence, it can be said that some share of the transportation costs is unavoidable by its nature from the point of view of a particular company. The reason is that even if Meconet orders no space, the vehicle would still travel to its destination and produce at least the net emissions, meaning the emissions that such a vehicle generates while travelling unloaded.

Different ways can be found concerning the methods to obtain raw emissions numbers per trip, three of which are the most remarkable. They will be arranged in order of complexity: from the least complex to the most.

Determination of greenhouse gas emissions as a parameter for the formula

Firstly, a purely mathematical technique can be used. According to Mathers, the number of grams of CO_2 emitted by a vehicle can be found via the following equation (Mathers, 2015):

$G = D * W * EF$ (1),

where G – the amount of greenhouse gas emissions in grams,
D – number of kilometers travelled by the vehicle in question,
W – the weight of the load in kilograms,
EF – factor to be found in (Mathers et al., 2019), which shows how much greenhouse gases a specific transportation mode produces per unit of mass-distance.

Secondly, there are freely available tools on the Internet that allow anyone to calculate the carbon footprint from a particular freight delivery. The weight of the shipment, transportation modes used, and distances between legs are the inputs, and the kilogram emission values serve as outputs. In particular, the EcoTransIT emissions calculator is an attractive option due to it using the European standard EN16258 as a basis for the emission calculation methodology (EcoTransIT, n.d.). The figure below shows the aspects the calculator considers to be EN16258 compliant.

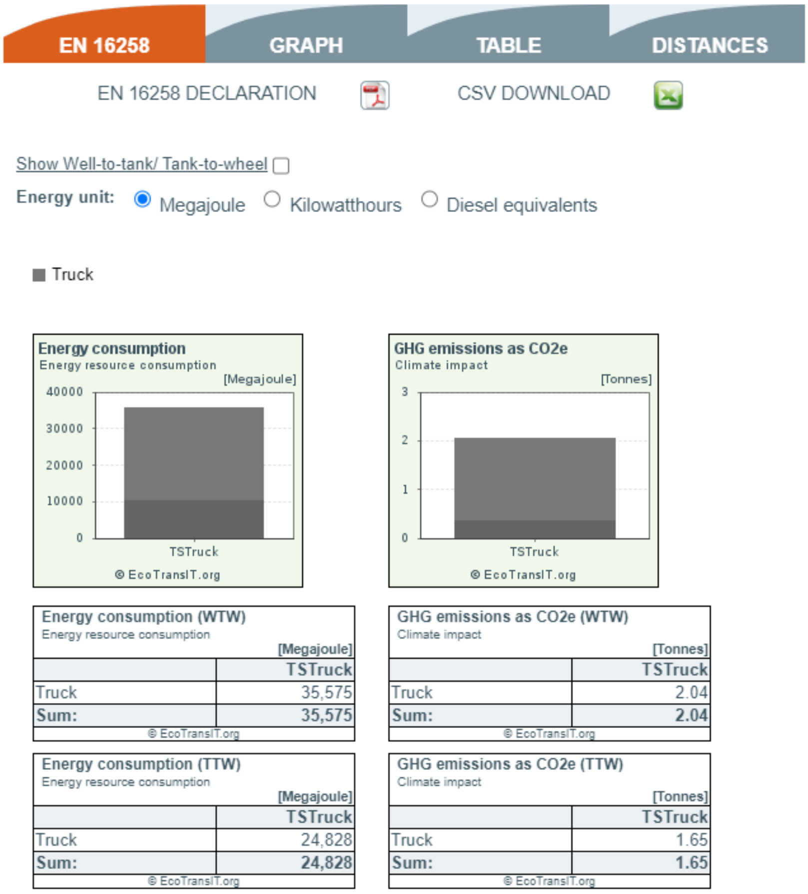

Figure 2. Example EcoTransIT calculation. (EcoTransIT, n.d.)

In addition, this tool incorporates the tools to calculate distances more precisely via using Google routing software. The picture below shows that multimodal deliveries also benefit from this feature. Nevertheless, route information can also be obtained from the logistics services suppliers due to the ability to add via points.

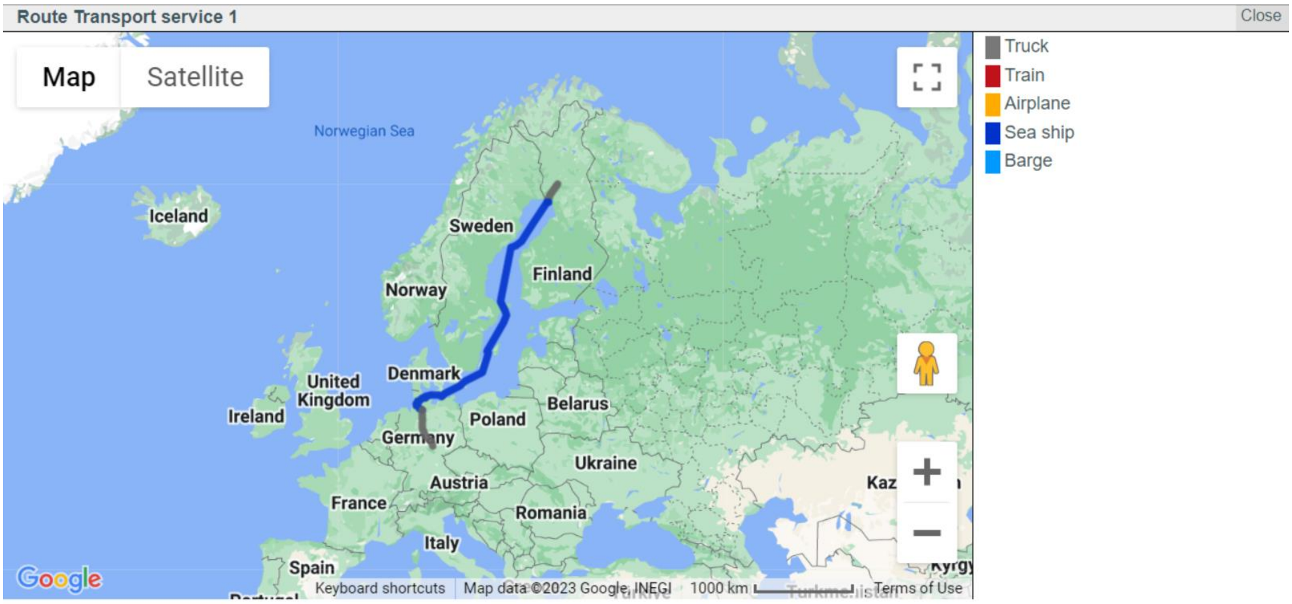

Figure 3. Example of routing a delivery from Rovaniemi, Finland to Erfurt, Germany.

Thirdly, specialized simulation software could be installed for detailed emissions calculation. Such a solution as MOVES can provide a mathematical model with precise inputs, outputs, and computational processes to produce, as the U.S. government states, the “state-of-the-science” result (USEPA, 2020). Single-vehicle routes are also available for modeling; however, the system always returns the output in mass per hour of operation (USEPA, 2020). The visual appearance of the

MOVES user interface is demonstrated below.

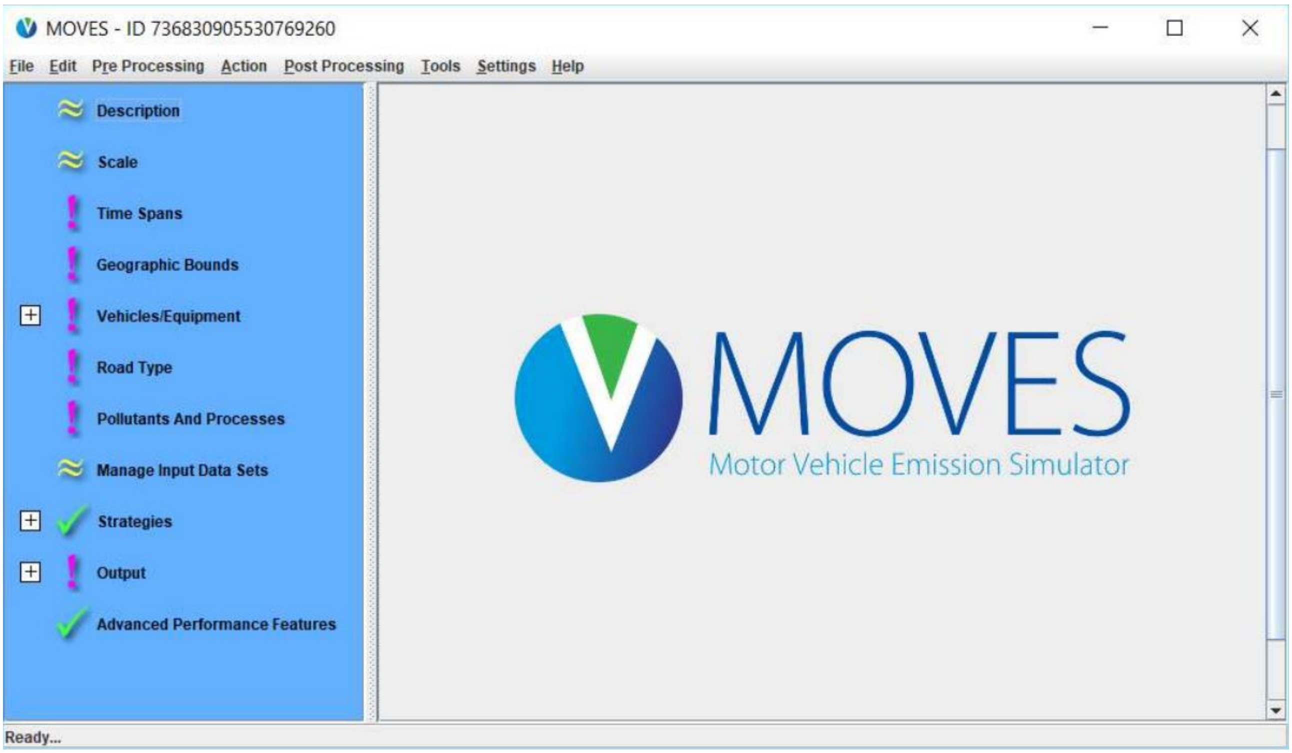

Figure 4. Example of MOVES user interface. (Claggett & Houk, 2018)

Determination of greenhouse gas costs as a part of the formula

Darma Wangsa defines long-term carbon emissions costs for shipping as those found according to the formula:

$\frac{D}{Q} * (ET_1 + ET_2) * C_{GHG}$ (2),

where D – average demand of the buyer [units/year],

Q – order quantity of the buyer [units],

ET_1 – transport indirect emission quantity [ton CO_2],

ET_2 – transport direct emission quantity [ton CO_2],

C_{GHG} – cost per ton of CO_2-equivalent emitted [€/ton CO_2] (Darma Wangsa, 2017).

Darma Wangsa refers to “direct emissions” as synonymic to “variable emissions,” while “indirect emissions” is synonymic to “fixed emissions.”

3.2 Emissions cost for rework in literature

For Meconet rework processes, the division of emissions into direct and indirect ones is also present, as scholars believe. However, their definitions are different in this case. The production process itself causes direct emissions, while the indirect's cause is purchased energy in full accordance with Scope 2 (Darma Wangsa, 2017).

Determination of energy spent for rework as a parameter of the formula

From the interview with several Meconet employees, it became clear that data collection concerning the rework methods of each particular defective batch is impossible to collect. Hence, this thesis utilizes an assumption that every reworked item undergoes every production process once again, and in terms of Scope 1 and 2 greenhouse gas emissions, reworking an item is equivalent to manufacturing another one from scratch. This assumption is due to Meconet's own requirement. The company has its intrinsic data on aggregate electric energy spending per item produced, while in this work, the imaginary parameter of 0,5 KWh/item will be used.

As an alternative, one item's emissions for all rework operations may be calculated as a sum of all greenhouse gases caused by burning fuel during said operation (Sarkar et al., 2018).

Determination of greenhouse gas costs as a part of the formula

The formula offered by Darma Wangsa appears as follows:

$$D * \left[\frac{\Delta I_1 * (e_{co} + s_{co} + h_{co} + c_{co}) * L_r}{n * Q} + \Delta I_2\right] * C_{GHG} \quad (3),$$

where D - average demand of the buyer [units/year],
ΔI_1 – industrial indirect emission factor [ton CO_2 per KWh],
e_{co} – electricity energy consumption [KWh],
s_{co} – steam energy consumption [KWh],
h_{co} – heating energy consumption [KWh],
c_{co} – cooling energy consumption [KWh],
Lr – energy loss rate [%],

n – the integer number of deliveries per one production cycle [times],

Q – order quantity of the buyer [units],

ΔI_2 – industrial direct emission factor [ton CO_2 per unit],

C_{GHG} – cost per ton of CO_2-equivalent emitted [€/ton CO_2] (Darma Wangsa, 2017).

Alternatively, this formula can be written as:

$$\frac{D}{nQ} * (EI_1 + EI_2) * C_{GHG} \quad (4),$$

where D - average demand of the buyer [units/year],

n – the integer number of deliveries per one production cycle [times],

Q – order quantity of the buyer [units],

EI_1 – quantity of indirect emissions [ton CO_2],

EI_2 – quantity of direct emissions [ton CO_2] (Darma Wangsa, 2017).

Koli Dey, Park, & Seok suggest using time as one of the parameters for the same formula:

$$\frac{\xi_{cx} * \epsilon_{Px} * R_{Px} * (T_1 + T_2)}{T} \quad (5),$$

where ξ_{cx} – cost per kilogram of CO_2-equivalent emitted [€/kg CO_2],

ϵ_{Px} – the amount of CO_2-equivalent produced when manufacturing 1 item [kg/unit],

R_{Px} – frequency of finishing items [units/time],

T – length of one production cycle [time units],

T_1 and T_2 – border points of an interval within the said cycle (Koli Dey et al., 2022).

3.3 Emissions-to-spending conversion in literature

Governments are able to stimulate businesses to reduce greenhouse gas emissions, among other policies, via emission accounting, i.e., by forcing companies to pay for a certain amount of said gases let into the atmosphere by its business processes. The most widespread types of such a measure are taxes on carbon emissions, mandatory emission caps, and emission cap-and-trade (Benjaafar et al., 2013).

In the European Union, the latter methodology has been implemented (Directorate-General for Climate Action, n.d.). The cap-and-trade policy implies that the economy is divided into industries, and the industries are given a shared emissions cap, exceeding which results in relatively large fines. The enterprises within an industry are given a limited number of allowances, each giving the right to emit one ton of CO_2 equivalent. The allowances are subject to inter-enterprise trade, and each ton of carbon dioxide costs a company the amount of money determined by supply and demand (Contreras, n.d.). Research has proven that such a policy is beneficial for reducing greenhouse gas emissions in the long-term perspective. Hence, one can expect the legislation to stay in power and be further reformed to better suit the needs of sustainability in the European Union (Beck & Kruse-Andersen, 2020).

Taking all the above mentioned into consideration, it can be stated that the price per unit of CO_2 equivalent mass is a volatile parameter. Meconet may need to constantly update it following the current situation in the allowance market. Average price value as a parameter for the formula will contribute to the removal of seasonality at least, and using price indexes may bring even more detail.

3.4 KPI formation in literature

Before developing the KPI in question, explaining the nature of a Key Performance Indicator in general is essential. According to Parmenter (2019), “Key performance indicators (KPIs) are those indicators that focus on the aspects of organizational performance that are the most critical for the current and future success of the organization.” Taking the CSRD regulations that are soon to come and increasing environmental awareness among both suppliers and customers (Newman, 2020), the environmental KPI described in this thesis falls well under this definition. A KPI can also be defined as a measure of some material attribute belonging to a business process or a system that serves as a sign of progress in some field of the company’s activity (Brundage et al., 2017).

Theoretical material on KPI implementation

In addition to the abovementioned definition, implementing such indicators requires more thorough analysis and hard work to commit the personnel. (Parmenter, 2019) recommends dividing the implementation into three stages. Firstly, the management ought to nurture the emotional involvement of their personnel. Secondly, the need to define the factors that are crucial for the company's success and need to be supervised daily arises. And lastly, the steps to be taken to achieve improvement must be determined. These and several other Key Performance Indicator implementation principles are depicted below.

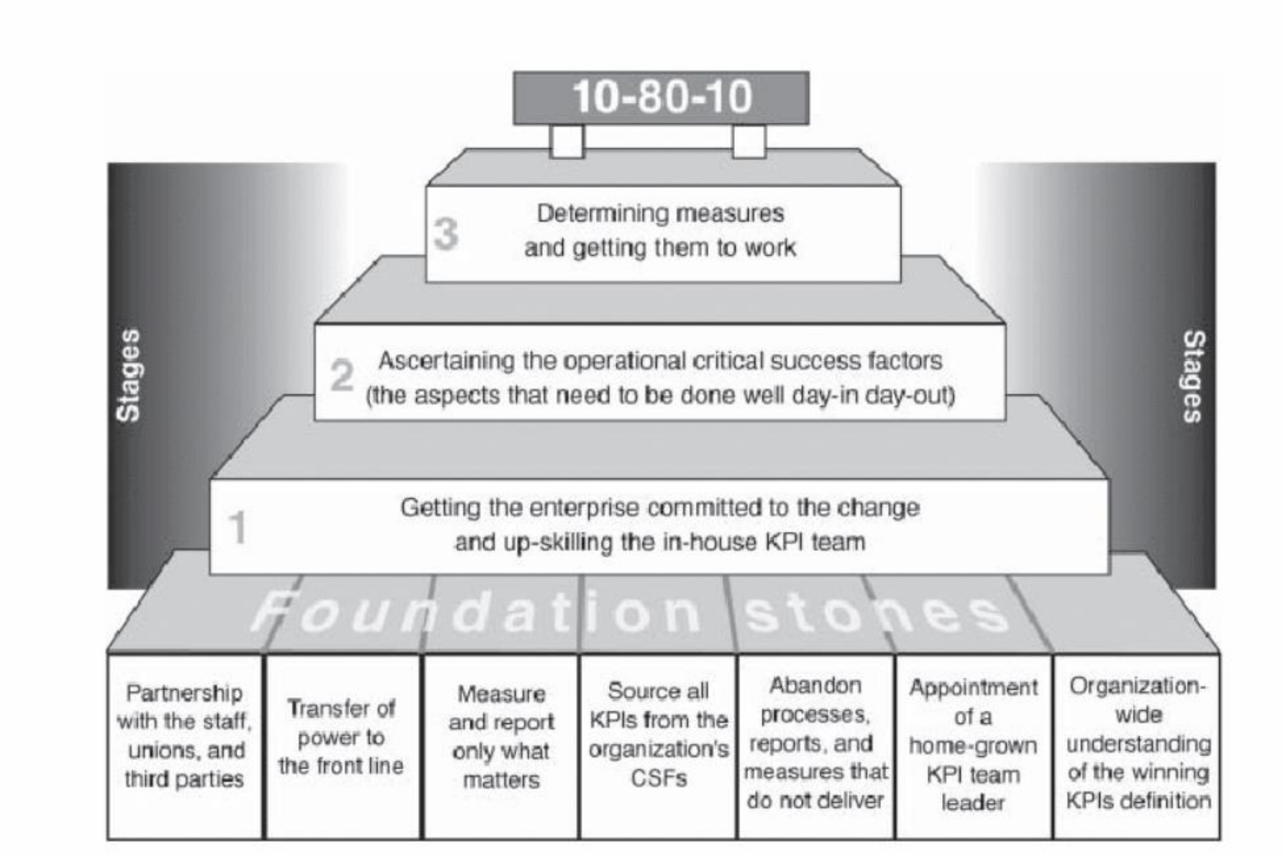

Figure 5. The Seven Foundation Stones in the Winning KPI Methodology. (Parmenter, 2019)

Additional characteristics for KPIs

A KPI is designed to measure, among other things, the Performance and Progress of the company in a specific field. Performance is the metrics on how the enterprise handles the matter in general, while Progress shows how the situation changed on the timeline.

Performance is given by the following formula:

$Pe = \frac{Value - Min}{Max - Min} * 100\%$ (6),

Where Pe – Performance value [%],

Value – current KPI value,

Min – the smallest value the KPI can take,

Max – the largest value the KPI can take (Savkin, 2014).

While Progress has its formula as well:

$\mathrm{Pr} = \frac{Value - Baseline}{Target - Baseline} * 100\%$ (7),

Where Pr – Progress value [%],

Value – current KPI value,

Baseline – the KPI value at the beginning of measurements,

Target – the KPI value desired by the company (Savkin, 2014).

Below the summary of the subchapter is shown.

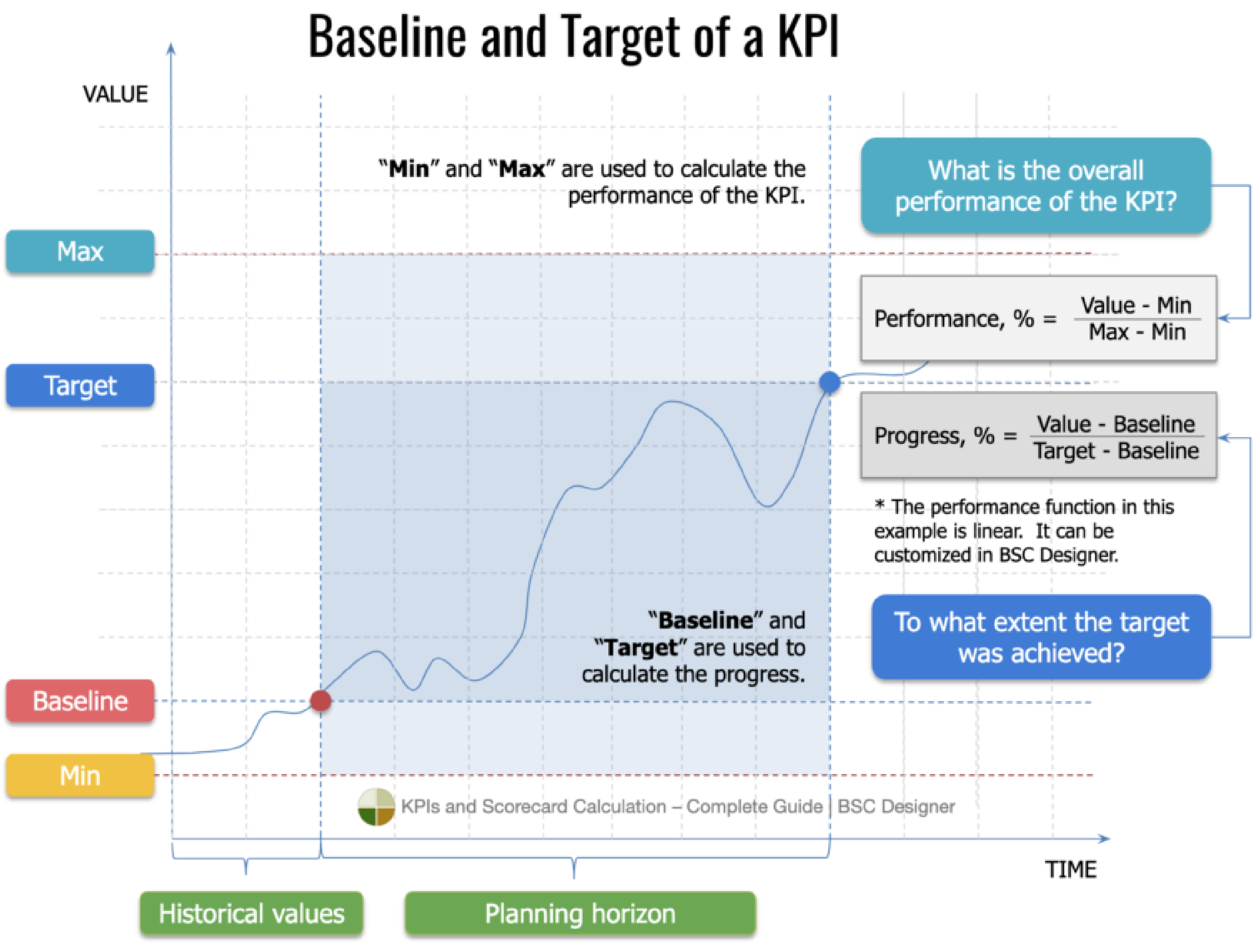

Figure 6. Illustration of KPI forming principles. (Savkin, 2014)

Legal basis for environmental KPIs

As a strict instruction to follow throughout this thesis, the European Parliament imposes its own regulations concerning what should be included in the mandatory sustainability reports. As the European Parliament & The Council of The European Union (2022), article 33, states, "information should also be harmonized, comparable and based on uniform indicators where appropriate while allowing for reporting that is specific to individual undertakings and does not endanger the commercial position of the undertaking." This should necessarily be taken into consideration when designing the KPI.

In addition, the same directive mentions that it is acceptable for the companies to publish within CSRD indicators related to the economic costs of their environmental influence. Another important part is that it is required to base the information provided on scientific evidence, which is one of the roots of importance for current and consequent research.

3.5 KPI visualization in literature

One of the definitions of information visualization is the visual demonstration of what the visualized data means. Its contiguous areas are software engineering, graphical design, and applied digital generation of informational representations (Al-Kassab et al., 2013).

Possible ways to visualize emissions

As a starting point, the following visual representation techniques have been shown to be appropriate (Team Geckoboard, 2020). The example values, and measures are given only for demonstration purposes and have no relation to the thesis.

- Line graphs:

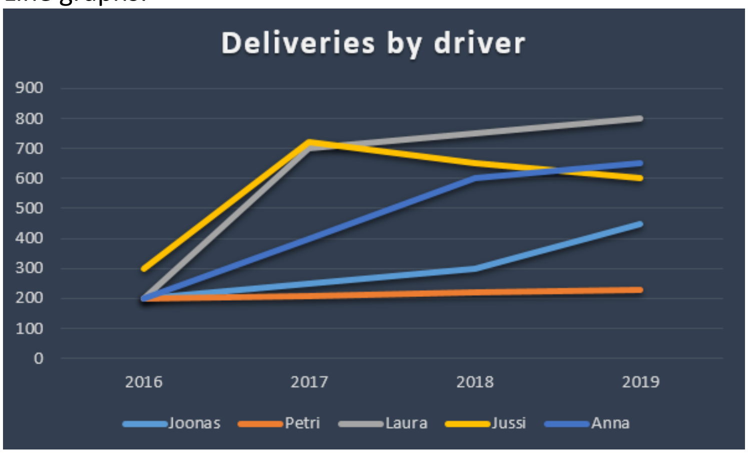

Figure 7. Line graph example.

- Gauges:

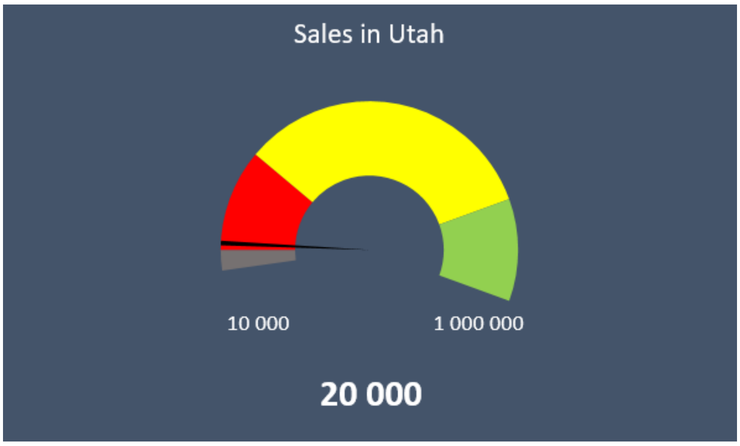

Figure 8. Gauge example.

- Bar graphs:

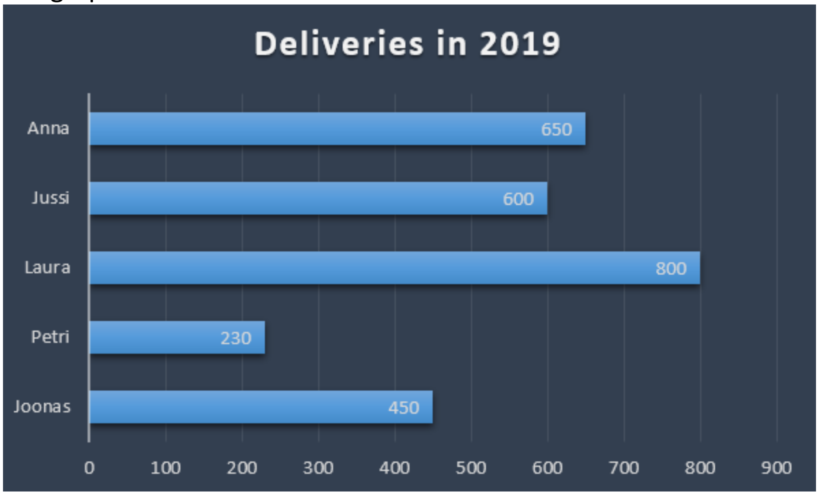

Figure 9. Bar graph example.

- Progress bars:

Figure 10. Progress bar example.

- Color-coded alerts:

Figure 11. Color-coded alert example.

Dos and don’ts of visualization

In order to present the data in the most convenient and beneficial way, (Shneiderman, 1996) suggests that the visualizing objects accomplish the aforementioned seven tasks:

1. **Overview.** Give an accumulated picture of the entire data set.
2. **Zoom.** Highlight the most influential parts of the set.
3. **Filter.** Hide items of no importance for decision-making.
4. **Details-on-demand.** Give more exact values when requested.
5. **Relate.** Show relationships between different actors.
6. **History.** Log the information acquired in the past.
7. **Extract.** Allow for the extraction of the smaller sets the visualizing object contains.

Moreover, working on the representation of data poses certain challenges. Firstly, the adaptation of the methodic for it to be appropriate for what-if analysis might be a demanding task for a designer. Secondly, showing many parameters complicates using some techniques (Brundage et al., 2017). Thirdly, it is crucial not to overload a decision-maker with information (Al-Kassab et al., 2013).

3.6 Meconet corporate information

3.6.1 Customer claim processing procedure

Understanding the needs to be numerically depicted is crucial for this study to obtain reliable results. In this chapter, the regular workflow happening after receiving a customer quality claim is described. By “claim,” any customer company activity aimed to notify that Meconet products have caused any harm or complications to the purchaser is meant. However, the understanding that actual employees' actions may differ from the model presented is essential for the reader. The source of this information is Meconet's internal documentation (Meconet Oy, 2022).

Claim receiving

When Meconet is notified of the quality issue, its addressee allocates a unique number to the claim. After that, an entry in the Excel file serving as a customer claim log and a separate shared Windows folder is created, and the claim number is used for its identification without linkage to the item code or any other product-specific information. The Excel entry contains unsophisticated data on the claim, while the Windows folder is purposed for the storage of official documentation.

An 8D report is also created to find the root cause analysis for the problem. In spite of that, the nature of 8D reports is out of this paper's scope.

Responsibility distribution

A technical handler is assigned to the claim after its receiving and number allocation. As a common practice, the person responsible for the process where the root cause was present is tasked with handling the complaint. For instance, if a packaging complication has caused the issue, a person from the order handling department will be responsible.

Claim handling

The newly assigned technical handler fills the Excel entry with general information. The information is extracted from the official documents and transferred into the claim log. This action marks the moment when the customer needs to be notified that Meconet has received the complaint.

At this stage, the potentially faulty batch is likely to arrive, and its processing is one of the top priorities for each company department. In perfect conditions, the final decision on how many items are actually defective is figured upon the consignment's arrival. When at least some items are proven to be defective, replacements are usually produced, or Meconet performs repairs. Concurrently, accounting actions, which are not covered by the thesis, are performed.

Claim closing

The decision of whether to close a claim or not is Meconet Quality Manager’s responsibility. They review the process at its end stage when the batch decision is issued and executed. In case the customer confirms that Meconet's response was satisfactory and all the possible corrective measures have been taken to solve the problem, the final edit is left in the Excel entry. The data that appeared during the claim handling and the Quality Manager's initials are added.

3.6.2 Description of the data sources given by Meconet

Customer quality claim log

This Excel document, among other data, contains information on the following defective batches information important for this thesis:

1. Receiving company
2. Receiving company address
3. Plant-manufacturer of the batch
4. Amount of items returned and amount of items to be reworked (zero if the claim proved to be groundless)
5. Method of handling the defective batch

These will serve as a basis for establishing numerous end formula parameters as well as the model database of distances between Meconet factories and their claimants.

Internal quality log

The document is an Excel spreadsheet filled by Meconet's own quality assurance department. It provides data on the coding, location, and, most importantly, the number of defective items detected during manufacturing. As even the internally found quality issues cause emission costs, this file will also be of use within this model.

Logistics suppliers’ emissions report

Data provided by transportation companies Meconet is a customer of include their total ton-mileage and total WTW-carbon dioxide equivalent emissions. These values will allow calculating an estimation of the emission rate per ton-kilometer travelled.

Table of delivered quantities

The total number of items leaving each factory is the closest obtainable value to how many items, regardless of the type, were produced on the site in question during the year. This number is crucial for calculating the direct emissions factor per item produced.

Meconet environmental KPI list

The amount of energy produced and consumed by each Meconet production site is presented in this spreadsheet. Moreover, the numbers specific to the Tallinn factory are provided in this document. As energy production is one of the activities having a considerable impact on climate change, consumption numbers will be of use for the end formula.

4 Analysis

As an introduction to this chapter, it has to be said that the KPI was chosen to be represented in yearly form and be calculated for each of Meconet's factories separately. The ground for such a decision is that the comparability of data would be superior over those of, for example, the monthly form or averaging values of all manufacturing sites. Moreover, this corresponds to Shneiderman's task 6 of a visual representation item, namely History.

4.1 Transportation emissions

Fixed (unavoidable) transportation emissions can be defined as the amount of greenhouse gases produced by the vehicle in question by making an empty trip from departure to destination. These can be omitted in the formula as those not affected by Meconet employees' performance.

Of the three abovementioned ways of defining emission mass from transportation, the EcoTransIT calculator seemed to be the most appropriate. Its usage requires only a limited number of data entries, different legs can be evaluated at once, a comprehensive set of possible transportation modes is available, and different interface elements are painted in various colors. This measure facilitates visual search (Chang et al., 2018) and hence streamlines the calculation process.
In addition, the other two methods possess certain features that distance them from being optimal for Meconet. Mathers' formula, while being excellent in and of itself, may lack detail for

Meconet's current needs, as the emission factors may be strongly affected by the development of propulsion technology in the upcoming decade. On the other hand, MOVES provides an extensive level of detail at a relatively low cost. However, the software's focus on the American transportation system lessens its usefulness for a European logistics employee.

It is important to remember that some Meconet suppliers of logistical services keep their own record of WTW (Well-to-Wheel) emissions caused by their activity. This fact means that the data on greenhouse gas masses can be extracted rather than computed by the commissioning company. EcoTransIT is chosen as a secondary alternative for the case when no supplier information is available, and for the sake of uniformness, WTW values will be extracted from this calculator.

The formula of emission costs given by Darma Wangsa is based on a company's total transportation activity, considers indirect emissions, and assumes that the demand and order quantities are fixed. These features must be removed to tailor the expression to Meconet's needs. The number of trips due to quality issues can be retrieved from the corporate data. Hence, there is no need for both demand and order quantity to be present in the formula. Indirect emissions can be omitted. As a consequence, the end formula will instead look like a sum of the greenhouse gas costs of every trip.

4.2 Rework emissions

As Meconet possesses the internal research on the amount of energy needed for the production of a single item, the method proposed by Sarkar et al. (2018) becomes unnecessary to use. Moreover, the mentioned research was done with the assumption that every item, despite its type, requires the same production processes and the same amount of energy to be manufactured. Such an assumption was inherited by this paper as well.

The rapid reconfiguration of the European Union energy supply system (Heflich & Saulnier, 2021) is likely to force any indexes of CO_2-equivalent emitted per every KWh produced to become obsolete rapidly. Hence, this data needs to be periodically updated by Meconet and serve as a parameter rather than a fixed value.

The formula proposed by Darma Wangsa, namely Formula 3, is again related to the yearly demand and fixed order quantity. This fact is to be tackled. By analogy with the transportation emissions costs, the spending caused by emissions due to rework will be calculated as the yearly number of remanufactured items multiplied by emissions caused by each and then multiplied by the cost of every ton of CO_2 equivalent. Both direct and indirect emissions need to be counted, as they relate to Scopes 1 and 2, covered in this study, without relation to Scope 3.

Despite being brilliant on its own, Koli Dey's solution, namely Formula 5, may not address Meconet's needs in the best way. The reason is that the level of detail it gives poses no usefulness for the task discussed in this study. Being able to calculate the intermediate value on some timeline does not contribute to employee empowerment, nor does it help in decision-making.

4.3 Emissions-to-spending conversion

According to the special request of Meconet, price indexes should not be used in this thesis due to the unnecessary complexity of the method. This leaves only the averaging emission quota prices as a valid conversion method. By removing the seasonality component of price volatility, the technique will allow the company better to compare the performance of different factories in different years.

The information on the current price per metric ton of CO_2 equivalent could be obtained via Meconet data on purchasing contracts if the company decides to start keeping records of those, which is not the case at the time of completion of this study. Alternatively, publicly open databases such as Ember (2023) can be used.

4.4 Information on general KPI principles

Due to the non-financial nature of KPIs (Parmenter, 2019), it is necessary to pick any other unit than pure euros or dollars to measure the new indicator. Hence, Performance or Progress metrics must be incorporated into the formula immediately. Such a change will give Meconet percent value instead of a monetary one, fulfilling the essential requirement for a Key Performance Indicator.

As for the three steps proposed by Parmenter, sustainability assuredly poses a crucial factor for Meconet's success. Inspiring initiative in employees is one of the subjects of this study. Many measures of controlling the metrics are already established. However, their constant improvement according to LEAN philosophy and actions to be performed for reducing emissions are still to be researched.

Last yet still critical, the CSRD requirements should be met when measuring Meconet's environmental performance. The final values provided must be relevant to the company's processes, comparable, and harmonized. No sensitive information should be disclosed unless directed so by the European Parliament or other relevant legal bodies.

4.5 Information on KPI visualization

The leading choice in the visualization matter is whether line or bar graphs would better suit Meconet's visibility and employee empowerment needs. Below is the comparison of the two with accordance to Shneiderman's seven tasks, given the assumption that different lines represent different factories on a line graph, while different bars represent different years, and each bar shows every individual factory's contribution:

1. **Overview.** A line graph allows one to look at the results of every year on a single picture, while a bar graph forces Meconet employees to observe each year's metrics separately.
2. **Zoom.** Both graph types possess advantages: a line graph gives more visibility year-by-year. However, the bar graph highlights data factory-by-factory.
3. **Filter.** Meconet can exclude bar graphs with years too distant to be relevant, which requires slightly more work in the case of line graphs.
4. **Details-on-demand.** As the KPI is recorded yearly, more exact values cannot be delivered and visualized, allowing the paper to omit this task.
5. **Relate.** A line graph, which allows one to see the entire set of years and factories, seems significantly superior.
6. **History.** Same as in task 5.
7. **Extract.** As in task 2, a line graph allows for easier historical extraction, and a bar graph – for easier object extraction.

What poses line graphs as the ultimately more preferable choice is their superior fitness for what-if analysis: extrapolation is possible when working with time sequences, which line graphs represent. Henceforth, line graphs will be implemented as the primary method of presenting the KPI as a time series. Progress bars can be used as a secondary method, showing the process of achieving Meconet targets, if any will be given. Color-coded alerts may also be helpful in case of a need to warn employees about issues appearing with the KPI in question.

In addition, secondary visualizing tools seem to be needed to enable employee empowerment. Namely, gauges and color-coded alerts can complement the main graph to show the emissions quality costs from different perspectives. Also, more than one line graph may be useful for fulfilling European legal requirements.

Gauges can be implemented to show both the achievement of the employees in terms of reducing greenhouse gas costs and the possible room for improvement. The idea is to show the difference between the current KPI value and the previous year's one with an arrow, while zero and the "best case scenario number" are the extreme values.

Colored alert messages, however, may be controversial for the purpose of employee motivation. In international labor culture, such univocal indicators are intended to be shown only when the worker's performance is the sole cause for their appearance, being an unnecessary, annoying element in any other case (Paananen, personal communication, April 24, 2023). Adding a contingent "negative range" for the gauge chart might be another solution.

5 Discussion of formula

5.1 Mathematical model

In the description of the process of mathematical expression of the indicator in question, deductive reasoning will be utilized. That is, "moving from a broad observation about a topic to specific details in support of that topic." (Nordquist, 2020). In the context of KPI, the formula in its general form will be presented first to then observe its integral parts and ways to calculate them more closely. Denotations and measurement units for all parameters in this chapter formulas can be accessed from Appendix 1.

The final value of the Key Performance Indicator will be computed according to the following principle:

$$KPI = \frac{C_1 - C_0}{\tau - C_0} * 100\% \quad (8),$$

where KPI – the value of the environmental Key Performance Indicator [%],

C_1 – environmental quality costs for the most recent time period [€],

C_0 – environmental quality costs for the starting time period [€],

τ – company target for environmental quality costs [€].

Costs as parameters for (8), both C_1 and C_0, are found from another formula:

$C = C_T + C_R$ (9),

where C – environmental quality costs for the year: either C_1 or C_0 [€],

C_T – costs inflicted by transportation activities [€],

C_R – costs inflicted by reworking/manufacturing activities [€].

It can be seen that here the duality of environmental quality costs acts: they comprise spending due to transportation and spending due to rework.

Transportation costs are expressed as a sum of emissions from each trip:

$C_T = (\sum_{i=1}^{N_T} EI) * C_{GHG}$ (10),

where C_T – costs inflicted by transportation activities [€],

N_T – number of avoidable logistical trips caused by quality issues [units],

EI – transport direct emission quantity [ton CO_2],

C_{GHG} – cost per ton of CO_2-equivalent emitted [€/ton CO_2].

It is important to note that the claims from the internal quality log will always have C_T equal to zero, as no transportation activity will be performed.

EI is found from the EcoTransIT calculator or computed according to the expression:

$EI = \frac{ER}{RM} * MC * DC$ (11),

where EI – transport direct emission quantity [ton CO_2],

ER – total emissions reported by the logistics services supplier for the year of calculation [ton CO_2],

RM – total ton-mileage reported by the logistics services supplier for the year of calculation [ton-km],

MC – the mass of the faulty consignment [t],

DC – distance to cover to deliver the faulty consignment back to the producing factory [km].

Rework costs are found following this expression:

$$C_R = Q_R * \left[\Delta I_1 * (e_{co} + s_{co} + h_{co} + c_{co}) * L_r + \Delta I_2 + \frac{E_G * G_h}{PV}\right] * C_{GHG} \quad (12),$$

where C_R – costs inflicted by reworking/manufacturing activities [€],

Q_R – number of items assigned to be reworked during the year [units],

ΔI_1– industrial indirect emission factor [ton CO_2/KWh],

e_{co} – electricity energy consumption per one item reworked[KWh],

s_{co}– steam energy consumption per one item reworked [KWh],

h_{co} – heating energy consumption per one item reworked [KWh],

c_{co} – cooling energy consumption per one item reworked [KWh],

L_r – energy loss rate [%],

ΔI_2 – industrial direct emission factor [ton CO_2/unit],

E_G – greenhouse gas emission index [ton CO_2/m^3 of natural gas burned],

G_h - the volume of gas burned within the internal heating system [m^3],

PV – number of items produced by the factory in question [units],

C_{GHG} – cost per ton of CO_2-equivalent emitted [€/ton CO_2].

It is important to note that only the items proven to be defective are remanufactured. Those which pass quality control after being returned incur only transportation costs. The number of items to be remanufactured is calculated according to a separate formula shown below.

$$Q_R = \sum_{i=1}^{N_q} Q_D \quad (13),$$

where Q_R – number of items assigned to be reworked during the year [units],
N_q – number of internal and external quality claims [units],
Q_D – number of items proven to be defective by quality control [units].

Separate parameters for each particular energy type and energy loss rate are needed, as different factories of Meconet possess their own energy consumption characteristics (Meconet Oy, 2022) and different energy loss numbers due to each building's unique properties in this relation. Moreover, heating and cooling consumption per item has to be calculated separately due to the volatility of average air temperatures in different years. The formula is universal for both heating and cooling:

$$\varepsilon_{t\_reg} = \frac{C_{sH}}{V_Y} \text{ (14)},$$

where ε_{t_reg} – energy spent for maintaining the temperature regime needed per item [KWh/unit],
C_{sH} – consumption of energy for heating or cooling during the year [KWh],
V_Y – total production volume during the year [units].

It is important to note that the claims with negative rework decisions (i.e., "false alarms") will always have C_R equal to zero, as no production activity will be performed.

Overall carbon gas emissions can also be calculated separately to obtain the pure ton number:

$$E_{total} = Q_R * \left[\Delta I_1 * (e_{co} + s_{co} + h_{co} + c_{co}) * L_r + \Delta I_2 + \frac{E_G * G_h}{PV}\right] + \sum_{i=1}^{N_T} EI \text{ (15)},$$

E_{total} – total greenhouse gas emissions caused by quality issues during the year [ton CO_2],
C_R – costs inflicted by reworking/manufacturing activities [€],
Q_R – number of items assigned to be reworked during the year [units],
ΔI_1– industrial indirect emission factor [ton CO_2/KWh],
e_{co} – electricity energy consumption per one item reworked[KWh],
s_{co}– steam energy consumption per one item reworked [KWh],
h_{co} – heating energy consumption per one item reworked [KWh],

c_{co} – cooling energy consumption per one item reworked [KWh],

L_r – energy loss rate [%],

ΔI_2 – industrial direct emission factor [ton CO_2/unit],

E_G – greenhouse gas emission index [ton CO_2/m^3 of natural gas burned],

G_h - the volume of gas burned within the internal heating system [m^3],

PV – number of items produced by the factory in question [units],

N_T – number of avoidable logistical trips caused by quality issues [units],

EI – transport direct emission quantity [ton CO_2].

5.2 Test calculation

Starting numbers

As per Meconet's internal data, each item is set to weigh 25,92 kg. In practice, shipment weights may differ depending on the shipments' contents.

Average price per one-ton permit, which are the main cap-and-trade policy assets, as found from Tiseo (2023):

$\overline{C_{GHG}}$ = 81,04 euro/ton

The target value is yet to be defined by Meconet. Hence, this paper assumes it to be:

τ = 50 euro

Emissions intensity per kilowatt-hour consumed in Finland as in Nowtricity (2023):

$\Delta I_1 = 1{,}46 * 10^{-4}$ ton/kWh

Same for Estonia (Nowtricity, 2023):

$\Delta I_1 = 5{,}51 * 10^{-4}$ ton/kWh

Emissions from burning one cubic meter of natural gas (Toniuc, 2019):

E_G = 0,0019 ton

The following data sample has been extracted from the company's documents for 2022:

$N_{T;1} =$ ## (unavailable in the public version due to confidentiality reasons)
$\sum_{i=1}^{N_T} EI =$ ## ton (unavailable in the public version due to confidentiality reasons)
Hence, transportation costs for 2022 in this case are:

$C_T =$ ## * 81,04 = 224,45 euro

Then, every case where there is any number of re-produced items will need a rework emissions assessment. An example case of one claim would look like this:

$$30 * \left[1{,}5 * 10^{-4} * 3 * 0{,}8 + 1{,}176 * \ 10^{-6} + \frac{0{,}002 * \ 30\ 000}{1\ 000\ 000}\right] = 0{,}0126 \text{ ton } CO_2$$

All numbers presented are imaginary due to confidentiality reasons.

Meconet data gives the following numbers on total production emissions caused by quality:

$$\sum_{i=1}^{N_R} = Q_R * \left[\Delta I_1 * (e_{co} + s_{co} + h_{co} + c_{co}) * L_r + \Delta I_2 \ + \frac{E_G * \ G_h}{PV}\right] = 1{,}268 \text{ ton } CO_2$$

Hence, rework costs for 2022 in this case are:
C_R = 1,268 * 81,04 = 102,78

Overall, 2022 costs are:
C = 224,45 + 102,78 = 327,23 euro

The Key Performance Indicator can now be calculated in the following way:

$$KPI = \frac{327{,}23 - 400}{50 - 400} * 100\% = 20{,}79\%$$

From this number, it is seen that Meconet has become ≈21% closer to its target value since the moment measurements started. This is the way how the progress can be measured and shown to employees to enhance their empowerment.

Details of the calculation

The calculations can be performed within any numerical database handling software such as Microsoft Excel or Microsoft Access. In this case, Excel was utilized by the author. However, the formulas and parameters are the same, and Meconet will be able to automatize the computations with any tool it sees appropriate.

Overall, the following general inputs are needed for the KPI value to be found, including both those described above and the confidential entries:

1. Price per ton of CO_2-equivalent
2. The constant value of the mass of carbon dioxide produced when burning one cubic meter of natural gas
3. Direct emission factor, i.e., how many tons of carbon dioxide are produced when executing operations for the production of one item. Items are assumed to undergo a uniform set of operations whose emission characteristics do not change from item to item
4. Tons of CO_2 emitted by the world's energetic system in order for Finland to consume 1 kilowatt-hour of electric energy
5. Tons of CO_2 emitted by the world's energetic system in order for Estonia to consume 1 kilowatt-hour of electric energy
6. The total amount of greenhouse gases produced by the logistics services supplier
7. The total amount of ton-kilometers provided by the logistics services supplier
8. Company’s emissions quality costs target
9. Baseline emissions quality costs value

The following factory-specific numbers are also required:

1. Yearly electricity consumption
2. Yearly heating energy consumption
3. Yearly natural gas consumption
4. The number of items that left the factory. It is assumed to be the closest number to the factory’s production volume
5. Energy loss multiplier of the building
6. Distances between the factory and the sites of claiming companies. They are found via the EcoTransIT calculator

In addition, claim-specific information needs to be gathered:

1. Customer address
2. Number of items in the batch which is claimed to be defective
3. Number of the defective batch’s items which are proven to be defective
4. Decision on the batch (produce new items or return the current ones)
5. Mass of an individual item in the batch (alternatively, the item code, which would refer to the BOM entry)

With this dataset, the progress achieved in a particular year towards a particular environmental target can be assessed. This method is, highly likely, not intensive in terms of computational power. However, it can be seen as data-intensive. The computational model built for demonstrational purposes can be observed in Appendix 2 (unavailable in the public version due to confidentiality reasons).

6 Discussion of visual representation

The line graph was chosen as the primary way to represent the Meconet advancement in reducing its quality emission costs. Apart from it, several secondary figures might be implemented to abide by the CSRD regulations and assist employee empowerment.

This thesis proposes the usage of three visualizing entries:

- Primary KPI line graph [KPI; year]
- Emissions-based line graph [E_{total}; year]
- Change “speedometer” [min value: 0; max value: 100%]

Figure 12. Primary graph example.

In the figure shown above, the X-axis represents years of measurement, while the Y-axis represents the percentage of eliminated costs in relation to the total number of costs to be cut. Each year's value is specified both on the axis and on the main line itself for the purpose of achieving comparability. The target level is represented by the additional line and the round sign: they clearly show that in order to reach the desired result, the line has to go in the upward direction. The caption above underlines the commonality of the cost reduction target for both the workers and the management. Differently colored elements help locate the needed piece of data as quickly as possible. Moreover, the target line painted yellow is likely to induce activity among employees (Yuk & Diamond, 2014). This graph can be used for internal employee information and publication within the CSRD framework, as it does not contain sensitive information. In the latter case, the source of the data needs to be indicated below (Yuk & Diamond, 2014).

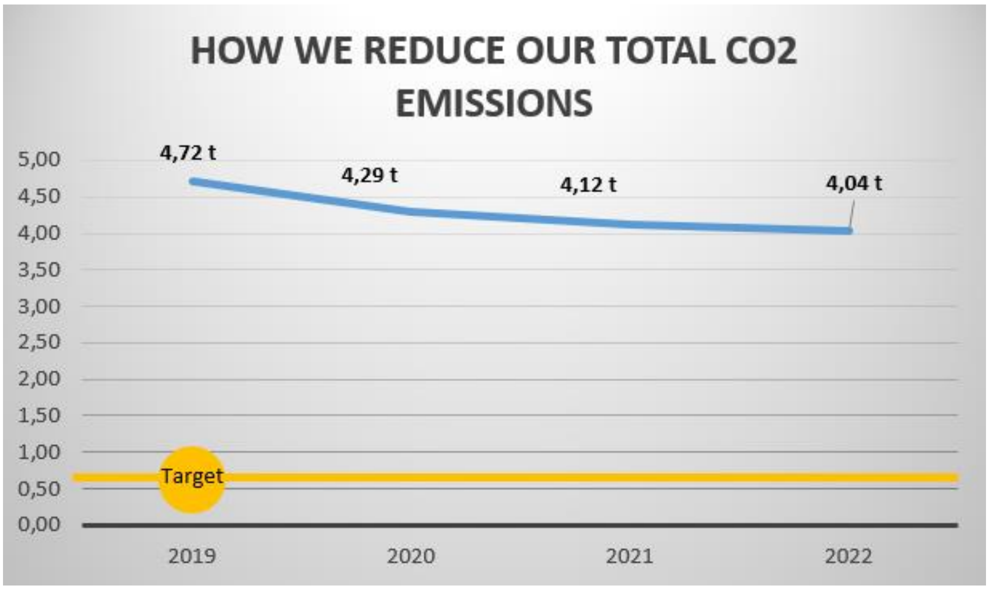

Figure 13. Emissions-based graph example.

The diagram above looks similar to Figure 9. However, several differences between them pose the emissions-based picture as a unique and necessary one. Firstly, the Y-axis is calibrated in tons instead of percentages to show real-life values. Secondly, due to the slower scale of change in emissions, compared to the change in the KPI ratio itself, value dots are replaced by value superscription for better visibility of the line itself. Thirdly, in this case, the target value is the specific value of E_{total} which provides a KPI value of 100%. In general, this type of visualization may be helpful for management information and communication with European authorities. Another remarkable feature is that by comparing the two line graphs, one can introduce an assumption about whether the cut in emissions quality costs is caused by the reduction in such emissions or the drop in permit prices.

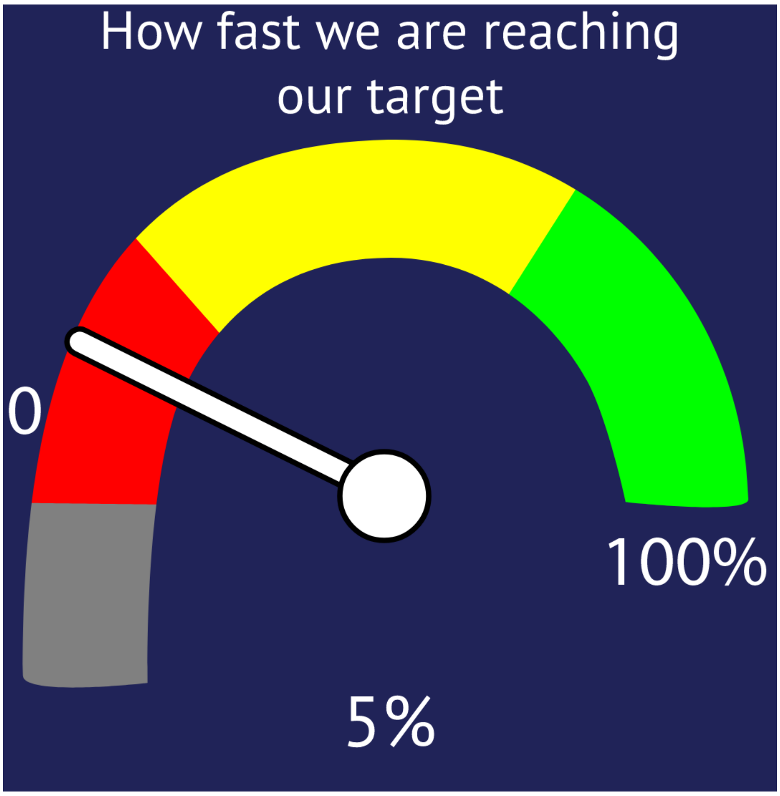

Figure 14. “Progress speedometer” example.

The third layout shows a “progress speedometer.” This chart can show the comparative evaluation of the company's progress using the difference between the previous and current year KPIs as input. For example, the arrow will point at this percentage on the gauge if the target became closer during the year in question by 5% (25% in 2021 versus 30% in 2022). If Meconet considers this “average speed,” the 5% score will be included in the yellow zone. Respectively, 1% of the 2022-2021 difference will be inside the red zone and 97% - in the green zone. In case the progress becomes negative (i.e., costs rise), the arrow will point to the green zone. A “speedometer” of this type will be of importance for internal communication between management and shopfloor workers. Its advantage is that it shows both achievements and room for possible improvement.

Other visualization tools can be implemented right away, yet the drawback is that they would require additional resources in terms of programming and design skills. For instance, a year’s total cut costs can be pictured as a certain number of equivalent commodity items, such as coffee cups or liquid detergent bottles. A bar chart also called an isotype chart, composed of different years’ results, will allow for both visibility and comparability to be present. By using pictograms for presenting numerical information, one improves the visualization’s memorability (Wilke, 2019), which is directly related to the purpose of employee emotional engagement. In addition, due to the number of small items akin to coffee cups being a less scalable value, changes will become more perceptible to a human due to Weber's law (Namboodiri et al., 2014). In the absence of the abovementioned human resources, only an external example of isotypic depiction can be shown below.

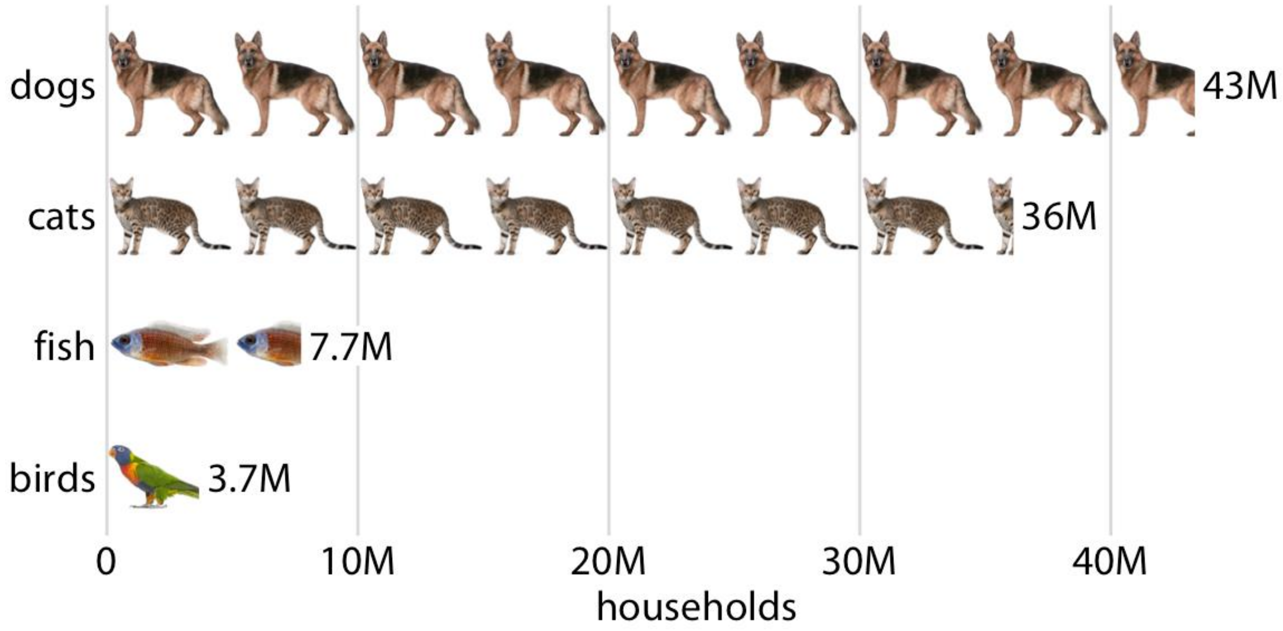

Figure 15. Example of an isotype graph. (American Veterinary Medical Association, 2012)

7 Results and conclusions

7.1 Recommendations for future development

7.1.1 System building recommendations

This paper presents a functional model for a system that calculates the environmental KPI. Nevertheless, the nature of Meconet business processes may require a more independent, automated environment to update the data needed to compute the indicator constantly. Such a development will, however, require technology and personnel available only to the case company.

Data collection and formula calculations can be automated via Microsoft PowerBI software, known for its ability to import data from different Microsoft Office formats, including Microsoft

Excel (Microsoft, 2023). This capability will enable Meconet to combine information from several of its sources without mobilizing substantial manual input capacities.

Most of the general information described in Chapter 5.2 will come from certain open Internet sources. Factory-specific information gathered yearly is evenly located in Excel and ERP sources. Claim-specific information will be almost exclusively extracted from Excel logs. Furthermore, this level of data organization will require a certain number of manual data entries.

On this schematic found in Appendix 3 (unavailable in the public version due to confidentiality reasons), the data listed in Chapter 5.2 is first inserted in primary sources, namely ERP and several Excel sheets. Three data entries are also found in the external web sources. After that, the PowerBI script tailored for this purpose reviews the primary sources, and this Microsoft software performs calculations for the year's production indirect emission factor and transport direct emission factor. With the use of all relevant inputs that are gathered by the script, stored by the PowerBI itself, and typed into it manually by the employees, the program calculates total emissions costs for a specific quality claim. The year's total quality emissions costs can be found by doing the same with each registered claim. The year's KPI is obtainable by combining this number, the target number, and baseline costs. This indicator value is valid for a single Meconet factory, and the process is to be repeated to obtain the metrics for each production site.

Though requiring only one manual input per claim, the described system is able to provide the indicator value for the year in question. The primary data sources need to be reviewed by the script yearly to achieve this. Inputs can be exported to Microsoft Excel or processed immediately within the PowerBI environment. In any case, there is a need for additional effort in visualization to finalize the results.

7.1.2 Accuracy improvement recommendations

Despite the mathematical model being assuredly ready for practical implementation, there is still room for enhancement of its accuracy. A number of parameters used by this model are rough estimations delivered by the company. Decreasing the level of aggregation for the data for both transportation and rework is likely to increase KPI values' traceability and comparability, as well as better observe the factors influencing the emissions costs and their dynamics.

In this paper, carbon dioxide permit prices are retrieved as monthly averages throughout the entire Europe. Higher accuracy can be reached by analyzing Meconet's transactions concerning buying the permits mentioned above. Extrapolating the permit prices over one year will give a more relevant C_{GHG} value.

Transportation emissions are calculated case-by-case, which gives an acceptable level of aggregation as of now. However, mileage-to-spending conversion is done with the use of an average rate. Several methods exist to improve the precision. Firstly, the rate per ton-kilometer can be divided into two analogical rates: for ground transport and sea transport. Secondly, Meconet can request information concerning fuel types and vehicle models its partner forwarding companies utilize. Thirdly, closer cooperation between Meconet and its logistics services suppliers can be initiated, meaning that digital tachographs and other possible fleet telematics devices will provide the case company with trip-to-trip emission values, either obsoleting the ton-kilometer rate or giving it a claim-specific nature. Either of these solutions or any combination of them will decrease the level of aggregation for transportation emission data.

Rework emissions might require additional research to retrieve more accurate and product-specific emission factors – both direct and indirect – and buildings' energy loss rates. Processes can be examined to associate a direct emission factor with each, and a civil engineering company can possibly check buildings for this purpose. As a preliminary final step, it might also be beneficial to calculate the amount of energy to be spent to produce one item out of each product category. Through such actions, the usage of average data will be substantially decreased. Hence, the KPI values will turn out to be more precise.

There is also a way of completely excluding manual inputs from the computational system, hence eliminating human factor from the process. Turning quality claims into product-specific by either providing the customer with the Meconet internal item number for the ordered batch or requesting employees to modify the ERP programming for associating specific orders with their claims (hence linking claims to their respective item numbers). In fact, any consolidation of data sources will increase the user-friendliness of the initial system. For instance, transferring the entire claim processing system and claim databases to the ERP environment may be a sound optimizing solution. Tasking the Quality Manager to assist with complaints handling in their early stages also falls under the term “consolidation,” as one person will be involved in the process from its start.

7.2 Prospects for further research

The mathematical and visual model described in this thesis compose an instrument ready to use immediately as an environmental KPI. In addition, with practical experience gained during its use, new approaches and data handling techniques can be found to improve the carcass built in the paper. New ways of collecting the numerical inputs described and adaptation of advanced ICT tools are also topics to consider for researchers when further discussing the results of the work’s application.

Direct emission factor, i.e., the amount of greenhouse gases entering the atmosphere whenever one item is produced, is also to be defined more precisely. As this piece of data is of particular importance for the calculation technique, it might be viable to launch another research concerning the environmental friendliness of Meconet industrial equipment as soon as the company seems possible. Universities and other public scientific institutions may also hold a certain interest in completing this task.

Moreover, the principles of the LEAN philosophy drive the commissioning company to improve its key metrics constantly. Hence, researching the influence of different factors on the indicator proposed is essential to detect what methodologies in reducing quality emissions costs are the most effective ones. Such studies can also assist other companies and public bodies in searching the ways to improve their sustainability policies.

Another important topic that motivated Meconet to commission the paper is employee empowerment. Qualitative research studying the workers’ reactions to the proposed form of visualization would help the company better understand how to perfect this way of motivation further and what unexpected responses there may be after certain changes in the KPI.

7.3 Reliability

This paper studies the construct of environmental quality cost metrics. Mathematical operations were chosen as a measurement method for this construct, with Meconet data and several data estimations as variables. Such a method provides a relatively small error probability and hence assures a certain high degree of repeatability, provided that the same values for the variables are used.

The external information, for the most part, was collected from written sources and thus can be reviewed by the reader. However, it is necessary to remember that a number of statements in this thesis were extracted from personal communications. Hence, they may contain personal bias to a certain extent. Even so, the nature of qualitative research allows the reliability of the thesis to remain sufficient for scientific consistency (Welch, 1985).

7.4 Validity

The validity of this research is limited by its case study nature. In other words, it has been tailored to the needs of a single company and adapted to its business process structure, including make-or-buy decisions. The use of the study results in future research is therefore limited. For instance, the fundamental architecture of the automatized KPI computational system is likely to require radical modification: at the minimum, the primary data sources will differ. As another example, if the company arranges delivery of its products using its own technical and human resources, data collection and emissions calculation will vary.

Nevertheless, the basic principles for building mathematical and visual environment can be implemented by other companies. These principles go as such:

- Categorizing the emissions quality costs, including yet not limited to transportation and rework categories
- Implementation of electronic computational machines as central tools for storing and processing KPI information
- Combining different sources of factual information to obtain the necessary data
- Usage of external software resources for vehicle routing purposes
- Utilizing managerial effort as a way of establishing the KPI
- Establishing the KPI as a non-financial value

- Usage of a variety of visualization tools for demonstrating a multi-perspective picture of the situation
- Usage of associative imagery and progress demonstration for employee empowerment

The propositions above are expected to serve as a universal basis for companies that plan to track their progress toward sustainable development and motivate their employees to take environmental responsibility.

7.5 Conclusion

In this paper, the following questions were observed:

i. How can Meconet numerically reflect its progress in achieving carbon neutrality in terms of quality?
ii. How to represent this reflection in a simple and understandable form?
iii. How will the resulting Key Performance Indicator benefit both Meconet's employee empowerment strategy and its abidance by the CSRD norms?

This thesis answers each one. The progress in obtaining environmental friendliness can be reflected through the use of several data sources combined into a single Key Performance Indicator reviewed yearly and separately for each factory. A comprehensible demonstration method would be through several line charts, a gauge chart, and a bar chart with certain associative imagery integrated. The Key Performance Indicator created within the development of this study is expected to engage employees in the ecological development of the company via progress reflection, memorability, and material associations. Compliance with the CSRD norms requires reporting non-financial performance indicators, which is the result of this thesis work.

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Appendices

Appendix 1. Parameters

KPI – value of the environmental Key Performance Indicator [%]

C_1 – environmental quality costs for the most recent time period [€]

C_0 – environmental quality costs for the starting time period [€]

τ – company target for environmental quality costs [€]

C – environmental quality costs [€]

C_T – costs inflicted by transportation activities [€]

C_R – costs inflicted by reworking/manufacturing activities [€]

N_T – number of avoidable logistical trips caused by quality issues [units]

N_R – number of rework orders caused by quality issues [units]

EI – transport direct emission quantity [ton CO_2]

ER – total emissions reported by the logistics services supplier for the year of calculation [ton CO_2]

RM – total ton-mileage reported by the logistics services supplier for the year of calculation [ton-km]

MC – mass of the faulty consignment [t]

DC – distance to cover to deliver the faulty consignment back to the producing factory [km]

E_G – greenhouse gas emission index [ton CO_2/m^3 of natural gas burned]

G_h - volume of gas burned within the internal heating system [m^3]

PV – number of items produced by the factory in question [units]

C_{GHG} – cost per ton of CO_2-equivalent emitted [€/ton CO_2]

Q_R – number of items assigned to be reworked during the year [units]

N_q – number of internal and external quality claims [units],

Q_D – number of items proven to be defective by quality control [units]

ΔI_1– industrial indirect emission factor [ton CO_2/KWh]

e_{co} – electricity energy consumption per one item reworked[KWh]

s_{co}– steam energy consumption per one item reworked [KWh]

h_{co} – heating energy consumption per one item reworked [KWh]

c_{co} – cooling energy consumption per one item reworked [KWh]

L_r – energy loss rate [%]

ΔI_2 – industrial direct emission factor [ton CO_2/unit]

ε_{t_reg} – energy spent for maintaining the temperature regime needed per item [KWh/unit]

E_{total} – total greenhouse gas emissions caused by quality issues during the year [ton CO_2]

C_{sH} – consumption of energy for heating or cooling during the year [KWh]

V_Y – total production volume during the year [units]

Appendix 2. Calculational model in Microsoft Excel

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Appendix 3. Automatic calculation system schematic

Please note that this appendix is unavailable in the public version.