A methodology to select energy-related key performance indicators (e-KPIs) for improving energy management in manufacturing industries: A case study in the paper industry

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Acknowledgement

"It was the best of times, it was the worst of times, it was the age of wisdom, it was the age of foolishness, it was the epoch of belief, it was the epoch of incredulity, it was the season of Light, it was the season of Darkness, it was the spring of hope, it was the winter of despair …"

1859 -- Charles Dickens

This quotation is the executive summary of my academic journey. It was harsh and labourious and sometimes depressing; but, the people along the journey made it worthy. My friends made it funnier, my professors made it interesting, and my sweetheart made it less discouraging.

I never thought that I would be able to write a master thesis, but my incredible supervisors - Paulo Pecas, Tania Sousa and Luis Esteves - made it easier. Thank you for everything. You will always be in my heart.

However, If I had to dedicate this thesis, it would be definitely to my mom, Liz, the one who made everything possible.

Abstract

In a competitive world, effective use of performance indicators and more meticulous monitoring and control of energy consumption are essential for achieving improved energy efficiency performance for current and future enterprises. The existing methods and norms on how to select energy-related performance indicators have been not able to relate energy-related indicators to the other company's indicators reliably. Therefore, the present dissertation proposes the use of a methodology to choose the energy-related indicators considering the company's overall strategy as well as the energy strategy. For that purpose, best practices tools from other fields were adapted to be more 'energy-friendly', such as Balanced Scorecard and Strategy Maps. The methodology has been applied to largest European Kraft mill leading to a new energy-related indicators network that considers the current indicators and proposes new ones that could significantly improve the decision-making process.

Keywords: Business Strategy, Energy Management, e-KPIs, KPIs

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Nomenclature

BSC – Balanced Scorecard

SM – Strategy Map

PDCA – Plan-Do-Check-Act

KPI – Key Performance Indicator

e-KPI – Energy Related Key Performance Indicator

KRI – Key Results Indicators

PI – Performance Indicators

RI – Results Indicators

1. Introduction

Energy resources are directly linked to well-being and prosperity across the globe [1]. Access to energy is considered as one of the critical factors for the development of organisations and human being [2].

Even though the importance of energy in the society, a recent report [3] exhibit that more energy is wasted than consumed, approximately per 1 unit of energy consumed 0.58 units are wasted. However, the rise of energy's prices, environmental laws and more demanding purchasing behaviours towards environmentally friendly products are forcing organisations to search for energy management systems that can improve the efficiency and effectiveness on how the energy is consumed [4].

To keep its competitiveness and satisfied the consumer, organisations around the world began to implement sustainability programmes for managing their energy consumption and fulfil the law [5]. However, a recent report released by Bain & Company [6] states that only 2 per cent of those programmes achieves or exceed their goals. The primary cause indicated is the disconnection between business objectives and sustainability objectives. Also, the same study [6] specifies that the factors that are critical for achieving the company's sustainability goals are: the commitment of the top management, the employee's engagement, and clear goals and metrics.

Currently, business strategies are commonly developed using management tools that facilitates their statements [7]. Nowadays, one of the most popular tools is the Hoshin Kanri [8–11], which is a methodology that uses two main tools, Plan–Do–Check–Act (PDCA) [12] and Catchball process [11], as a medium to indicate and align the company's objectives across the different hierarchical levels. However, it does not give guidelines on how to communicate the objectives and monitor its achievement [13]. Therefore, generally, after applying it [8,14], organisations use the Balanced Scorecard (BSC) framework to help in strategic communication and metrics selection process. The BSC [15] categorised the objectives by the most significant organisation's areas and stipulated that for each objective stated one metrics should be attributed to it.

To achieve the company's objectives, the statement of the goals and metrics is not enough; it is crucial to [16] ensure the cause-effect relationship between goals and Key Performance Indicators (KPIs) and guarantee that they are connected to the mission to accomplish. However, for that purpose, the BSC alone has been proven insufficient [15]. Hence, it is necessary to use other tools to guarantee the interconnection of the goals and metrics.

The authors of the BSC proposed [17] the use of an Strategy Map (SM) framework to visualise how the organisation's goals and metrics are correlated. The SM [15,17] is a framework that places each objective and metrics according to a category and highlights the interconnection between them.

Nowadays, the literature calls [18–20] the most important metrics for assessing the achievements of the objectives in an organisation as KPIs. KPIs can be defined as the most significant variable in an organisation that help to assess how far a company is from achieving its objectives.

Regarding KPIs related with energy management, a recent literature review performed by May G. stated [5,21] that there five significant gaps that the current Energy-Related KPIs (e-KPIs) are not being able to address and lead to weak energy management systems. (i) Few of the proposed KPIs are suited for energy management; (ii) The benchmarketing between organisations its not always possible; (iii) The e-KPIs do not report how the energy is being used; (iv) Conceptual frameworks for selection and use of KPIs underdeveloped; (v) Decision supporting tools for e-KPIs are rudimental.

Even though BSC and SMs are well-established tools for developing the business strategy, during the research process, no study was found that proposed them as a medium for an organisation to develop its energy strategy management or as a guide for obtaining and managing e-KPIs. Therefore, to overcome the preceding stated limitations and to consider the gaps identified by May G [5], this work proposes adaptations to BSC and SM frameworks to create a sophisticated tool to develop an energy management system for selecting and control e-KPIs. It is considered manly the management of energy in an organisation due to the value of the energy sources, the environmental impact it has, and the available information.

To accurately applied adaptation to the frameworks, in state of the art section, the current methods for developing and deploy business strategies are described, as well as the methods and guidelines to select KPIs. Additionally, in the same section, the contemporary knowledge of e-KPIs is presented, continuing with the current methods for their selection and the gaps they are not able to address.

With the knowledge assembled, a methodology for the selection of e-KPIs is given, in the methodology section. The present methodology considers that the organisations already know what their sustainability mission is. Therefore, no adaptation to the Hoshin Kanri methodology will be proposed.

To test the methodology, a two-month internship in the most significant Paper Manufacturing Company in Europe was conducted in order to collect information to generate an e-KPI network for the cooking pulping process. All the information gatheras well as the result obtained is presented in the field work section.

Taking into consideration the above-mentioned, it is expected that the present disseratation contributes to:

- Find a method to select (energy related Key Performance Indicators) e-KPIs.
- Document the characterization of the e-KPIs
- Construction of a KPI network, in a real environment, paper & pulp industry

2. State of the Art

In this section, the basic knowledge needed to develop an e-KPI network is presented. As previously stated, to effectively develop an KPI network, there must be an organisational structure founded on a well-defined strategy [22]. Therefore, an established instrument for developing and implementing a company's strategy is described through the Hoshin Kanri methodology, which gives guidelines and tools to states annual strategic directress and goals. The literature says [18] that in order to evaluate the goals implementations, it is necessary to attribute them metrics so they can be assessed over time. For this purpose, the BSC (Balanced Scorecard) and Strategy Map (SM) frameworks are described because they are an recognised tool [15] to link the company's strategic objectives to the most important organisational metrics, KPIs [18]. However, along the years, it was noticed that different objectives lead to different metrics, which lead to a broad diversity of indicators. This diversity created the requirement for standardisation norms to analyse them. For energy management, the norm attributed is the ISO2240, which defines [23] how an e-KPIs (energy-related Key Performance Indicators) should be described in manufacturing industries. Since this norm does not give guidelines on how to select the e-KPIs, two of the main guidelines for selecting KPIs, B Marr and Parmenter, are presented and compared. Finally, a brief history of the use of e-KPIs is given, as well, as three different methods to select them are explained.

Hoshin Kanri

According to several authors [8,12,24,25], one of the primary challenges within an organisation is linking the top-management goals to the operational management across the different organisational levels; often what is achieved is different from what was planned, so to overcome this challenge, methodologies to align the organisation towards the same goals were developed. The first one to appear, 1963, and to become commonly accepted was the Hoshin Karin methodology [12].

Hoshin Kanri is a strategic planning methodology that when correctly applied enables the strategic organisational management across different hierarchical levels and different hierarchical functions by uniting the efforts of the whole organisations to achieve the critical objectives of the organisation [13]. The fundamental philosophy of Hoshin Kanri is that each employee in the organisation, independently of his role or his hierarchical level, should contribute with his daily work to the accomplishment of key-factors/priorities for the organisational success [13]. The Hoshin Kanri methodology is based on two essential points: The statement of annual directress composed by goals, target points, and strategical priorities and deployment of targets using the top-down and bottom-up approaches [9].

To simplify the implementation of the Hoshin Kanri methodology, a modern framework called Hoshin Planning summarises the seven-step that an organisation should follow to apply it correctly [26]. As shown in Figure 1, the process begins with the statement of the vision/mission of the organisation that must be objective, achievable and time-related [27]. Then, top management should state the critical objectives to achieve the vision – these objectives, usually, require the effort of every single person within the organisation. Afterwards, these "big objectives" are broke down into annual goals. The execution of the yearly goals begins at top management, and then propagates to each employee; this process is called Goal Setting. During this phase, the annual objectives are discussed and adapted to the team's reality through a process called Catchball. After understanding the organization's goals, teams can implement them. Finally, the advances toward the annual objectives need to be monthly reviewed to ensure that the plan is being correctly executed. At the end of the year the organisation should made a debrief to evaluate if the goals were achieved and improvement possibilities [8,26].

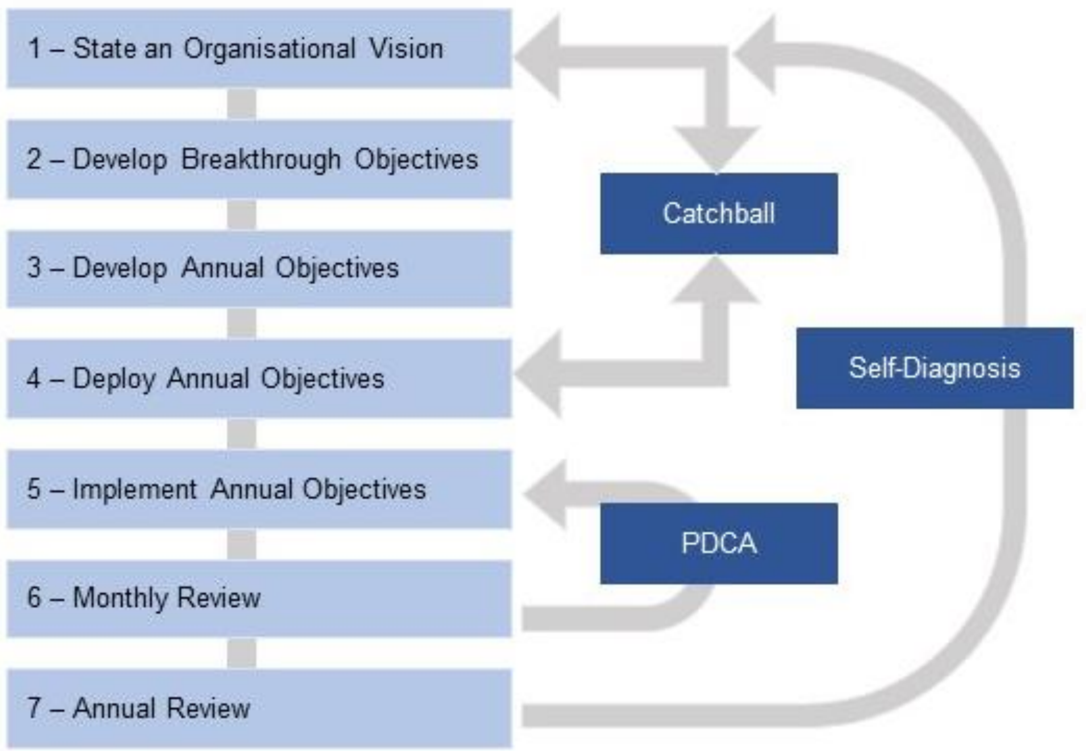

Figure 1 - The core of Hoshin Planning Process [13]

As Figure 1 shows, at the deployment stage, a powerful communication tool addressed as "Catchball" is executed. The Catchball process prevents the sub-optimisation or local optimisation without taking into account the overall company performance, i.e., it guarantees that the objectives of the organisation do not overlap and each team's work addressed the intended objective. The name Catchball has its origins in a children's ball game where a ball is thrown from kid-to-kid. The same mechanism is used at organisations, where different parts of the organisation review annual objectives through an iterative process of discussing. The process starts at the highest management level and, then going down to lower levels until a consensus is reached. The multi-directional feedback and multi-flows of information ensure the commitment of all employees towards the company's goals.[11].

When implementing the objectives, the PDCA Cycle is a necessary tool to ensure the correct implementation of Hoshin Kanri. The PDCA Cycle, or "Deming Cycle" as often called is a daily management tool that drives the strategy across the organisation and guarantees that the goals are accomplished. It provides the principles and procedures for the systematic pursuit of knowledge and improvements [8,12,26].

The four steps of the PDCA Cycle are [26]:

- Plan: Propose a change or a test aimed at improvement, once the origin of the cause of the problem is determined.
- Do: Carry out the modification or the analysis, preferably in a pilot or on a small scale.
- Check: Evaluate if the desired result was accomplished, what or if anything went wrong, and what was learned.
- Act: Adopt the change if the desired result was obtained. If the results are not as desired, repeat the cycle using knowledge accumulated.

In summary, the purpose of Hoshin Kanri is that all members of the organisation have a clear understanding of the organisation's vision/goals through the Catchball process. With all organisation's members in perfect alignment and well understanding how their work affects the achievement of the company's annual goal, it's imperative the use of PDCA as a daily management tool, so the optimal productive power of the organisation can be accomplished [27,28].

Even though the Hoshin Karin methodology advice the statement of metrics for each organisational annual goal, it does not provide a guideline on how to select those metrics. Therefore, after an organisation applied the Hoshin Kanri methodology, it is common the use of the BSC framework as a medium to aid the selection process of the company's KPIs. In the next section, this framework will be presented, as well as, the SM framework, which is a complementary tool of the BSC [29].

Balanced Scorecards

In this section, the most widely used management strategy system framework is presented, BSC. This framework is specifically relevant for this thesis because it attaches a KPI to each strategic goal, simplifying the creation of a KPI network.

In an attempt to exhibit the connection between organisation's strategic goals and each operational sector, Robert Kaplan and David Norton published in 1998 an article called "The Balanced Scored Cards - Measures that Drive Performance". The general ideas in this article laid the foundation for the BSC strategic management, which become one of the most widely used strategies performance management frameworks [18].

The BSC framework aims to translate the global strategy of a company into actions by monitoring the strategic execution [30]. The BSC gives a framework for defining strategic objectives, measures and actions, within four crucial perspectives, providing managers with a more balanced presentation of financial and operational measures, thus the name. The four perspectives highlighted by the BSC are [30,31]:

- Financial: highlight the goals that intend to increase the financial value of the organisation and the ones that guarantee its financial viability;
- Customer: indicates the objectives that must be achieved in order to guarantee consumer satisfaction by aligning the company's actions with the consumer's interest;
- Internal: outline the goals that search for the excellence of the company's processes ensuring the satisfaction of the consumers and stakeholders;
- Innovation and learning: it covers the intangible resources of the company, such as know-how, human capital, information, leadership and culture. It intends to create a prosperous environment for innovation, employee fulfilment and growth of the enterprise by assessing employee's performance

The authors consider the division of the strategy in four essential dimensions as indispensable for the proper future performance of the enterprise [31]. Figure 2 exhibit the BSC framework to ease its comprehension.

Perspective	Objective	Metric	Target	Initiative
Financial				
Internal Business Process				
Learn & Growth				
Customer				

Figure 2 - Balanced Scorecard framework

In a BSC approach, an organisation should is state its strategic goals for each of the four perspectives, then set metrics, target values, and specific initiatives (measurable) for each one of them. After establishing the goals, companies should exhibit their objectives using the BSC framework to precisely express the company's strategy to their employees and managers, so the workforce can take actions aligned with the company's goals [18].

Though the acknowledgement that the BSC represents a fundamental change in strategic management, early attempts to use it led to extreme results, either the company was propelled to success or burden with bureaucracy and dismal results [15,29]. The difference between failure and success was often in the selection of the metrics used to measure strategic execution. To address this issue, Kaplan and Norton published in 2000 another article called "Having trouble with your Strategy? Then Map It" [17] where is proposed the utilisation of a SM to guarantee the causal relationships necessaries to execute the strategy. Through the visualisation of the causal links, managers could easily asses the correlations of different objectives and metrics.[17,18,31].

Kaplan and Norton’s article led to the creation of a framework called Strategy Map (SM). This framework intends to be an assessing tool for the correlation between the different objectives by highlighting the different objectives’ relationships. Figure 3 exhibits the SM framework proposed by D. Norton and R. Kaplan;

It important to remark that the authors of the SM advices to apply it before completing the BSC and only after stating all the perspectives’ objectives and choosing a metric for them [31],

According to R Kaplan [31], when developing an SM, the first step is to state the organisation’s mssion at the top of the framework and then filled it from top to bottom, each perspective at the time. The first perspective is the financial one because if the organisation is not financially viable, it will close doors (in the case of a non-profit organisation, the framework is rearranged - for example, placing it at the bottom). Inside this perspective, the financial objectives should be placed accordingly to two types of the category: growth revenue or productivity strategy. The growth revenue category has two possible components: build the franchise with new revenue incomes and increase value to existing customers by intensifying engagement with them through expanded sales. Likewise, the productivity strategy also has two components: Reducing the cost of structure - direct and indirect cost - and use assets more efficiently by reducing the fixed capital needed to sustain a given level of business.

After the placement of the financials’ objectives, the link between each objective and the big goal should be clear. If there is not a clear link, the objective should be removed and replaced with others

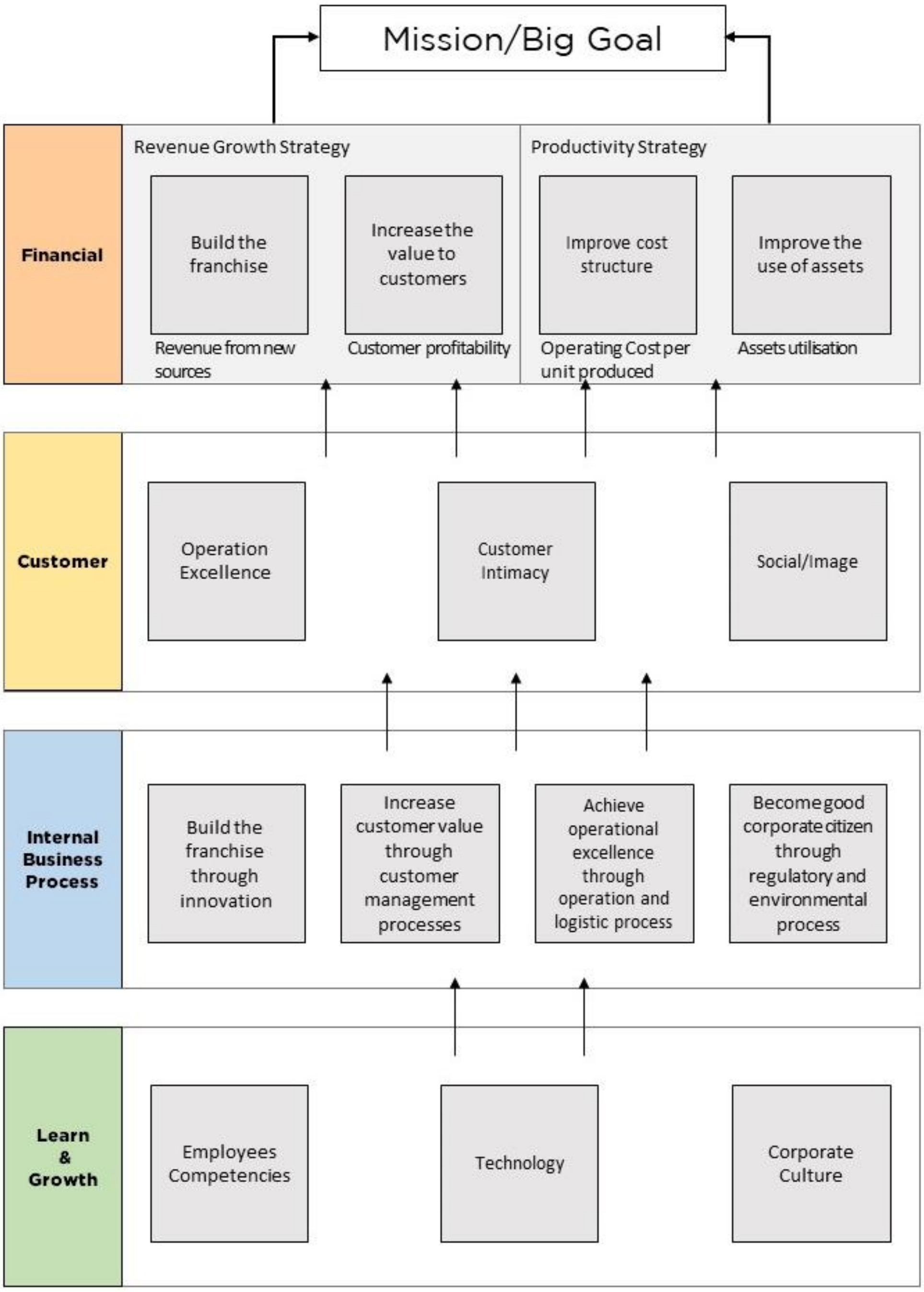

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Figure 3 - Strategy Map, taken from Concept Foundation of BSC, Kapan R [28]

The second perspective to be filled is the customer one. The reasoning behind it is that the organisation can only reach its financial objectives if it can deliver its value proposition to its customers. Generally, the customers' objectives of an organisation are among three categories: operational excellence, customer intimacy, and product leadership. Pragmatically, organisations strive to excel in one of the three areas while keeping threshold standards in the other two. The customer's objectives should be placed according to one of the categories and then tied them to one or more financial goals. If the customer's objectives cannot be linked to the financials' objectives, they should be replaced with ones that can.

For achieving the organisations' value propositions, the internal business process need to occur. Therefore, the next perspective to be filled is the one related to the business process. The internal process perspective captures the critical activities of an organisation. The business process objectives can fall into four high levels of process areas

- build the franchise by inventing new products and services and by entering new markets and customer segments
- increase customer value by developing relationships with existing customers;
- accomplish operational excellence by improving supply chain management, the cost, quality, and cycle time of internal processes, asset utilisation, and capacity management;
- Become a virtuous corporate citizen by establishing productive relationships with external stakeholders.

The internal business process objectives should be placed according to one of the categories above and then tied them to one or more customers goals. If the objectives cannot be linked, they should be replaced with ones that can.

The last perspective to be filled and the one that it is the foundation of the strategy map is the learning and growth perspective. This perspective represents the centre competencies and skills, the technologies, and the organisational culture needed that an organisation's strategy should have to accomplish its objectives. Primarily, the objectives should enable an organisation to align its human resources and information technology with its strategy. The organisation must determine how it will satisfy the requirements from internal processes, the differentiated value proposition, and customer relationships. The learning and growth objectives should be placed according to one of the categories above and then tied them to one or more internal business process' goals. If the objectives cannot be linked, they should be replaced with ones that can.

After ensuring that there is a continuous connection between the objectives and metrics to the company's mission, the rest of the BSC framework can be completed, i.e., state target for each metric and initiatives to achieve the target.

The amalgam of these concepts, the SM and the BSC, combined with more recent developments, have built the new BSC strategic management system [15,17]. The use of these frameworks give a more balanced view of their organization, beyond the typical financial measurements.

Even though the framework gives a tool to select the company's objectives and metrics under the same page, it does not provides information on how to select those metrics. In the literature, there are some guidelines to select the most important metrics of organisations, labelled as KPIs Since the metrics obtained by the BSC, and SM framework are the most important metrics of each perspective for now on they will be addressed as KPIs. In the next sections, the KPI concept will be further described and the norm for their development will be presented.

Key Performance Indicators

As above-mentioned, the KPIs are a collection of chosen indicators that exhibit the performance of an organisation and its progress, i.e., they estimate how far an organisation is from its strategic targets and help keep track of critical aspects related to the organisation's future [18]. It is of utmost important to remark that KPIs are nor goals neither objective to achieve; KPIs are a collection of indicators that summarise the business's performance providing a guideline to workers to recognise where the company is relative to its purpose, reflecting a broader, lucid, and informative image of the performance of the organisation [18,29].

To correctly use KPIs, in an organisation, each operational area should have its own performance indicators that provide specific information on their business process, this commonly leads to a wide range of typology of indicators – vast taxonomy. Therefore, to analyse them and to benchmark them, there is the necessity of standardisation [23].

Due to this need, the International Organization for Standardization created norms that provided frameworks for defining, composing, exchanging, and using KPIs, which enabled the benchmarking of the organisation's performance over an extended period and related it with similar companies. The norms were designed for specific industries and process. For example, the ISO 22400 "focuses on performance measures found to be particularly meaningful for the realisation of operational performance improvement. These performance measures can be achieved through combining various measurements from operations and forming what is called KPIs" It intends to be computed using data from the control domain and to provide the company and the Manufacturing Operation Management (MOM) with decision support information [10]. The resulting KPIs from this framework are related to personnel, material, equipment and process segments. The material also incorporates consumable materials like energy and additives/utility. [10]

Even though there are specific norms for the standardisation of KPIs, there is common ground for the definition and characterisation of KPIs. In the following section, it is going to be studied how to characterise a KPI and how to validate it.

2.3.1 Characterisation of Key Performance Indicators

According to the norm ISO 22400, before a metric can be considered a KPI for the manufacturing industry, it must be characterised regarding its content and context. By specifying this information [23], the organisation guarantees that the KPIs has a connection with the business's process, it is well-defined and it has a person/business unit responsible for it. For easier the characterisation process the norm prosed a framework to be fill with the required information. Figure 4 gives an exemple of the framework all ready filled.

KPI Description	
Content	
Name	Utilization efficiency
ID	10089
Description	The utilization efficiency is the ratio between the actual production time (APT) and the actual unit busy time (AUBT)
Scope	Work unit
Formula	Utilization efficiency = APT / AUBT
Unit of Measure	%
Range	Min: 0%; Max: 100%
Trend	The higher the better
Context	
Timing	On-demand, periodically, real-time
Audience	Operator, supervisor, management
Production methodology	Discrete, batch, continuous
Effect model diagram	See Figure 4
Notes	This indicator identifies the productivity of work units. Because only the production time affects an added value which will be paid by the market, the goal should be to get a high indicator value.

Figure 4 - Completed ISO 22400 framework example for stating a KPI for manufacturing process [14]

The content information assures that the KPI is unique and well-defined, enabling the responsible person to know the importance of the KPI, while the context gives information about how and when the KPI is measured, from whom, what are its constraints and its application [23]. Both information is equally important, and the KPI is only stated when all the data is collected.

A crucial part of the information framework is the effect model diagram [31], which higlights the elements/variables that influences the KPI directly and indirectly. Figure 5 gives an example of the effect model of Figure 4. In an effect model the relationship between the variables and the KPI must be highlighted by an effect arrow, stating which realtionshop they have.

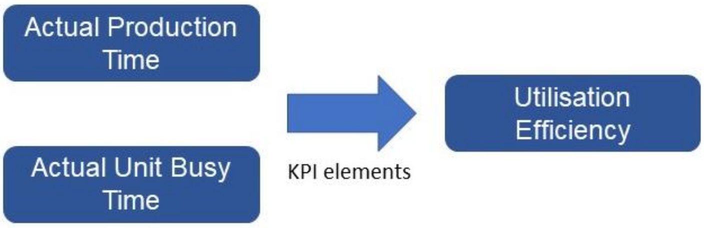

Figure 5 – Effect Model Diagram for Utilisation efficiency KPI [25]

Effect diagrams are [25] a useful tool for assessing which variables have influences over a specific KPI and to what degree they influence it. They are crucial to develop an e-KPI network because they outline the variables that affects directly and indirectly the measurement of the e-KPI.

2.3.2 Criteria for KPI

The research shows [18] that a typical problem in an organisation is to select which indicators are suitable to be used as for KPIs, i.e., in an organisation, there are thousands of indicators and it is difficult to choose which ones are KPIs and which are not. Hence, the ISO 22400 [23] created a list of criteria that a metric must check for being considered a KPI. This list follows the opinion of the leading experts in the field of KPIs, as R. Parmenter or B. Marrs. According to ISO 22400 [23], the criteria are the following:

- **Aligned:** The company strategy connects to the KPI.
- **Balanced:** It should be the metric that better describes the system within a set of parameters.
- **Valid:** It must be defined accordingly to the standard regulation.
- **Quantifiable:** The value of the KPI must be numerically specified.
- **Accurate:** The measured value should be close to the real value.
- **Timely:** The KPI must be accessible in real-time, where real-time depends on the operational context.
- **Predictive:** The KPI can predict non-steady-state operation.
- **Trackable:** The measures that affect the KPIs are known, documented and accessible.
- **Relevant:** The KPI enables performance improvement in the target operation, demonstrate real-time performance, forecast events, and describe the past of the process.
- **Correct:** The KPI compared to the standard definition (if one exists) has no errors concerning the standard definition.
- **Unambiguous:** KPI’s definition is well established.
- **Automated:** The KPI’s reporting must be automated.

- **Buy-in:** The teams related to the KPI (upper and lower levels) are willing to support the use of the KPI.
- **Documented:** The KPI must be characterized/documented
- **Comparable:** The KPI must be comparable over a period.
- **Understandable:** The KPI must be understood by team members, management, and customers.

2.3.3 Usefulness of KPI

As before mentioned, KPIs assess how far an organisation is from its target position; additionally, KPIs could have other uses in an organisation. In this section, is outlined the broad profitability that a KPIs could have if well-implemented [29].

Since KPIs summarise the relevant performance in an organization, they can be used as an instrument for facilitating the decision-making process. [18,19]. Also, if they are monitored constantly, KPIs could be a communication channel that allows supervisors/executives of an organization to transmit to their team how their work is influencing the enterprise's goals [32].

The visual perception of how their work affects the KPIs increases the feeling of commitment/responsibility among employees [32]; consequently, specific actions for improving the process are idealized. Each action takes into account the effect on KPI(s). The actions that do not have relevance in the KPI(s) should not be executed because of the risk of not generating value for the company [18].

Keeping track of the KPI can be used as a prevention tool by anticipating possible issues that may appear in the system. Monitoring KPIs over time exhibit the execution trend of a system, which facilitates managers to anticipate the achievement of targets, and if trends are not aligned with the organization's strategy, take actions to prevent them. Furthermore, KPIs also help to assess when is the best time to conduct maintenance work in equipment and systems because their trends emphasize the change in performance which can be linked to deterioration [18].

Employing KPIs as a prognostic tool can be used to test an hypothesis. Since KPIs display the action's results in a system, they establish a causal-link between execution and outcome. However, this use of KPIs can only be made if there is data prior to the measure being taken. Therefore, it is advisable that an organization is familiarized with KPIs before using them as a hypothesis tool [18].

Lastly, another noteworthy use that KPIs could have is as a competitors benchmarking tool [19]. Benchmarking is the process of comparing how an organization achieves its goals relative to other company or process [33]. By using KPIs as a benchmarking tool, they can exhibit this kind of situations so companies can be aware of their position regarding their competitors [34].

In summary, the main advantages of correct implementation and definition of KPIs are:

- Motivates the employees to search for new techniques or methods to improve KPI performance.
- Gives the organization a communication channel that exhibits vital information.
- Since employees can see how their daily actions affect the KPI, it is expected a deeper work engagement.
- Evaluates the performance of decision taken in a business process
- Benchmarketing possibilities in the long run.
- Assessing tool for the decision-makers in their strategic planning.

2.3.4 Common errors in the implementation of a KPI network

As pointed before, KPIs have several uses. However, the KPIs selection process is complex and strenuous [35] . In the following list, some of the main challenges that an organization faces when selecting KPIs are outlined [27,29]:

- Occasionally, organizations do not have a clear strategy.
- Unbalance vision of the whole organization - too much focus on financial indicators.
- Lack of the Catchball methodology, i.e., an essential parameter for a department can be irrelevant for another.
- Lack of knowledge of the selection process of KPIs.
- Insufficient data for obtaining the chosen KPI.

The most common errors when selecting KPIs are [18,29] :

- Measuring everything that is possible to measure, which results in too much irrelevant data.
- Measuring data that other organizations measure without assessing if that information is vital for the company's goals.
- Not choosing the relevant KPIs for the organization's strategy.
- Not involving the decision-makers in the selection process.
- Not outline the KPIs from the rest of the indicators.
- Not attributing the KPIs to the responsible employee.

In general, the abovementioned critical factors are transversal for KPIs. However, the KPIs for energy management have some particularities that are studied and review in the next section.

Guidelines for the selection and exhibition of KPIs

As pointed before, the KPI selection could be a complicated task. Therefore, in the following section, two general approaches on how to select and manage KPIs are described.

2.4.1 Bernard Marr Guidelines

According to Bernard Marr [18], when selecting KPIs, there are two possible categories: operational and strategic KPIs. Operational KPIs are measurements that evaluate how the execution of the business process is usually happening - typically, they are measuread close to real-time. While strategic KPIs seek to monitor or to forecast the direction towards a stated organisational mission. In the past, the strategic KPIs were measured at a higher pace than the operational KPIs. However, technology advances are changing this trend, and the frequency of measurements is becoming as close to real-time. For example, if a person tries to lose weight, a strategic KPI could be the person's weekly weigh, and an operational KPI could be the number of calories he intakes per meal. These two types of KPIs are equally [18] that the successful implementation of KPIs depends on the inter-link between operational and strategic KPIs.

During the selection phase, Marr [18] stated that there is not a fixed number of KPIs because they are based on strategic and operational objectives. However, he advises, as a thumb rule, that a company must aim for between 15 and 25 for high-level KPIs, that is, for the decision makers, and then extrapolate numbers for each business unit.

B. Marr [18] also points out that the method for the collection of data needs to be well structured because it influences the outcome result. The two types of data that can be measured is quantitive and qualitative. Quantitive data is mainly used when the measurement is numerical, while qualitative data is used when opinions or emotional states want to be assessed. Ideally, an organization uses both because one without the other can introduce bias in the measurement system.

2.4.2 David Parmenter Guidelines

Different from B. Marr, his contemporary Parmenter proposes [29] a new division for the categorisation of KPIs in order to simplify the selection process of the relevant metrics in an organisation. The categories he proposed are:

- Key Result Indicators (KRI) are financial aggregated indicators that describe what are the organization’s results, by comparing the KRI with the best possible mission result.
- Result Indicators (RI) are related financial indicators that indicate what the organization has achieved.

- Performance Indicator (PI) are not financial metrics that exhibit to an organization what to do.
- KPI are non-financial indicators that show what an organization needs to do for increasing its performance dramatically.

An example that Parmenter uses to illustrate the difference and relationship between these four types of parameters is an analogy with an onion. The onion's outside skin describes its overall condition, i.e., the number of nutrients, sun and water that it has received, and how it has been treated from the harvest to the supermarket shelf. – the analogy compares the outside to a KRI because it exhibits the aggregated result of the whole process. Nevertheless, as the onion is peeling the layers came out, and it is possible to find more information about its state. Regarding an organisation, the layers represent the various performance and result indicators. Finally, when the core is reached the current state of the onion is known, the core represents the KPIs. As the example illustrates, what separates KRI from KPIs are layers of PI and RI that are essential for understanding what separates the aggregated organisation's results from the best performance possible.

The selection guideline that Parmenter proposed is called the 10/80/10 rule, which states that an organisation should use 10 KRI, 80 PI and RI, and 10 KPIs.

For Parmenter, the 10 KRI should be reported to the company in the form of a board, summarising the most critical company's information. Then, regarding the 80 PI and RI, they should be standardized and reported according to the infield needs. Finally, in order to surpass the complexity of selecting only 10 KPIs, the organisation should state 30 KPI and progressively remove those ones that are not that relevant.

This model is primarily used for selecting high-level KPIs in the business control and management field.

2.4.3 Comparison of B. Marr and D. Parmenter Guidelines

The two guidelines described aid the KPIs selection process and gave some directions on how to present them. Nevertheless, the foundation the KPI selection is a reliable company strategy. In the following table, it is highlighted the key point of each author

Models	Marr	Parmenter
Typology of indicators	Operational KPIs Strategic KPIs	KRI; RI; PI; KPI
Nº of Indicators	10 or 15 for top management, and a similar number for each business unit	10/80/10
Frequency of measures	Operational KPIs: Real-time Strategic KPIs: weekly or monthly	Measured daily and presented in a monthly spectrum

Table 1 - Comparison of B. Marrs and D. Parmenter guidelines

Even though D. Parmenter and B. Marrs divide the indicators into different groups – D. Parmenter in result and performance indicators and B. Marrs strategic and operational indicators -, it is noteworthy the similarities in the division. Both authors divide the indicators into two groups; one group should be measured with a high frequency, near real-time, while the other group only need to be measured with a low frequency, monthly or semesterly. Also, one group is focused on the organisation results, i.e., what the company is achieving at the moment while the other group is related to the long-term company's vision, what the company wants to achieve. Considering the division, it is possible to conclude that there are two classes of indicators in an organisation, one for the top-management that provides information about the company's strategy, and another one class that helps to asses the tactical decision of an enterprise. Therefore, when stating the KPIs, it is crucial to evaluate what types of information provided, so they can be divided accordingly to the hierarchical level they address.

Besides the type of information, at first glance, both authors appeared to have different opinions about how many KPIs a network must contain. However, if the KPIs and KRIs are considered top-management, D. Parmenter states that they must be 20 metrics for top management and for lower levels 80, while B. Marrs states between 10 - 15 metrics for top management and similar numbers for lower hierarchical levels. Depending on the hierarchical division, the number of metrics for lower hierarchical levels could be the same. Therefore, a guideline to construct a KPI network could be 10-20 KPIs for top management and a similar number per business area.

Lastly, even though each author has its own opinion about the frequency of how the KPIs should be measured. It is possible to conclude that both guidelines state that the KPIs should be measured as frequency as possible and needed, so the person that uses the information to make decisions has the most information at his disposal.

Evolution of metrics for Energy management

Since measuring energy efficiency is the first step to effective energy management in production [21], in the following section, the importance of energy-related information is studied. This section covers findings of the role of key indicators for energy management purposes.

Over time, investigators often highlight the link between natural resources and organisations growth [36–38]. Moreover, Houthakker H. and Sollow R. stated that an organisation's growth is connected and limited by the availability of finite resources [38]; the study perceives energy as an indispensable resource input in any organisation's production. More or less at the same time, Allcott H. and Greenstone M. were able to identify the financial value that energy savings could bring to an organisation [36,37]. Nowadays, energy efficiency, as a sustainable corporate behaviour, is seen as a crucial lever for global competitiveness in the future [39]. Therefore, the industry in general, as well as policymakers, are prioritising the better management of resources in their agenda [40].

According to May G., it is crucial for all manufacturing companies to depend on a system to manage energy efficiency in production management [5]. This concept was also supported by Friedrich K. that stated that the organisational performance, particularly environmental and economical, is closely linked to management quality [39]. Hence, it is possible to link the relationship between energy efficiency and good management practices [41].

In an attempt to create an effective energy management system, over the years, energy efficiency indicators have been developed and applied [42,43]. In the literature, the more typical indicators for energy management are: specific energy consumption defined as the ratio of energy consumption to units and energy intensity is defined as the ratio of energy consumption to a monetary value [18,35,42].

To establish common ground in the scientific field, some researches [43] attempted to standardise the characteristics that KPIs should have by proposing a sustainable manufacturing measurement infrastructure. Later, in 2008, Boyd G. explored different ways to measure energy efficiency performance, having as a work field a steel plant and pointed out the usefulness of these key indicators for benchmarking the energy consumption within a plant [44]. In the same year, Tanaka K. proposed [45] metrics called 'energy-production signatures' for assessing the total energy consumption to production output at different levels, so decision-makers could evaluate the energy inefficiencies and also benchmarking the energy consumption performances in manufacturing plants. Two years later, Bunse K highlighted the [4] importance of integrating energy efficiency metrics into management operations, particularly emphasizing on the improvement potential at the machine tool level. Also, at the machine level, Paris J. [46] proposed a methodology for the selection of KPIs, through a dimensional analysis of the process equipment in a pulp mill using the Buckingham Pi theorem, this methodology had as a case study an Eastern Canadian Kraft mill, and several improvements projects were proposed leading to 30% potential energy savings [47].

To summarize the available knowledge at the time, May G. performed a literature review where it is suggested a KPI classification system accordingly to three dimensions: (i) Aggregation level: the degree of information that a KPI holds on; (ii) decision level: what types of decision will the KPIs help to assess; (iii) scale: the impact that the KPIs will have in the organisation . Table 2 summarised the dimensions and the relations between attributes of these dimensions. Specifically for e-KPs, Bunse K and May G. [41] as well as other authors [42], classify them as thermodynamic, physical-thermodynamic, economic-thermodynamic, economic-physical, or eco-efficiency [5].

Aggregation Level	Decision Level	Scale
Aggregated	Strategic	Organization
Disaggregated	Tactical	Work Center
Process	Operational	Work Unit

Table 2 - Dimensions used for classification of energy-related KPIs adapted from May et al. 2013 [5]

Even though the primary motivation for the implementation of e-KPIs is saving cost, some authors suggest that other valences of KPIs work as a catalyser [18,29,48]. For instance, the fact that KPIs can be used as a benchmarketing tool or a preventing tool it is seen as a competitive advantage [49]. Likewise, the current environmental awareness is making governments impose environmental legislation to the manufacturing industry, which means that organisations structured data systems to corroborate that they follow the law [40]. Moreover, increase cost of energy and the more responsible behaviour of customers could be perceived by organisations as an incentive for the use of e-KPIs [39]. In the presence of the beforementioned, it is possible to conclude that e-KPIs is a trend in the manufacturing industry.

Even though the increasing awareness in e-KPIs, there are significant gaps and industrial needs that need to be addressed to facilitate their implementations and manage [21]. The main gaps identified by May G. are [5]:

- The information required to compute the proposed e-KPIs is impossible/unpractical to collect or too costly, which creates a strong barrier for the implementation of e-KPIs.
- Due to the lack of data or variation of data, in manufacturing industries, it is not possible to use e-KPIs as a benchmarketing tool.
- The literature proposed KPIs are too aggregated to give specific information on how the energy is being managed.
- The current conceptual Framework does not provide information on how to select or manage the e-KPIs. For instance, the ISO22400 only helps in the characterisation of e-KPIs-
- Regarding energy management, the decision-making tools related to e-KPIs are undeveloped.

Taking in to account the beforementioned, it is possible to conclude that e-KPIs are a trend in manufacturing industries because their correct development and implementation could have a tremendous impact at different levels: energy bill, legislation, customer’s perception and innovation. However, as pointed by May G., some challenges need to addressed to obtain the benefits of its implementation. Considering this, in the next section, some methods for developing, manage and control energy systems are described.

Method for development energy management systems

As outlined by the governments of Canada and South Africa in their energy programs [50,51], the development of energy management systems is guided by a sequence of steps that follows a bottom-up approach: (1) monitoring consumption; (2) setting targets; (3) identifying and correcting faults; (4) motivating staff to conserve energy; (5) identifying and implementing energy-saving measures. Figure 6 gives visual support to elucidate the bottom-up approach, the blue line represents the common path that organizations follow when develop an energy management strategy while the orange line represents the execution of the strategy from the top to the bottom.

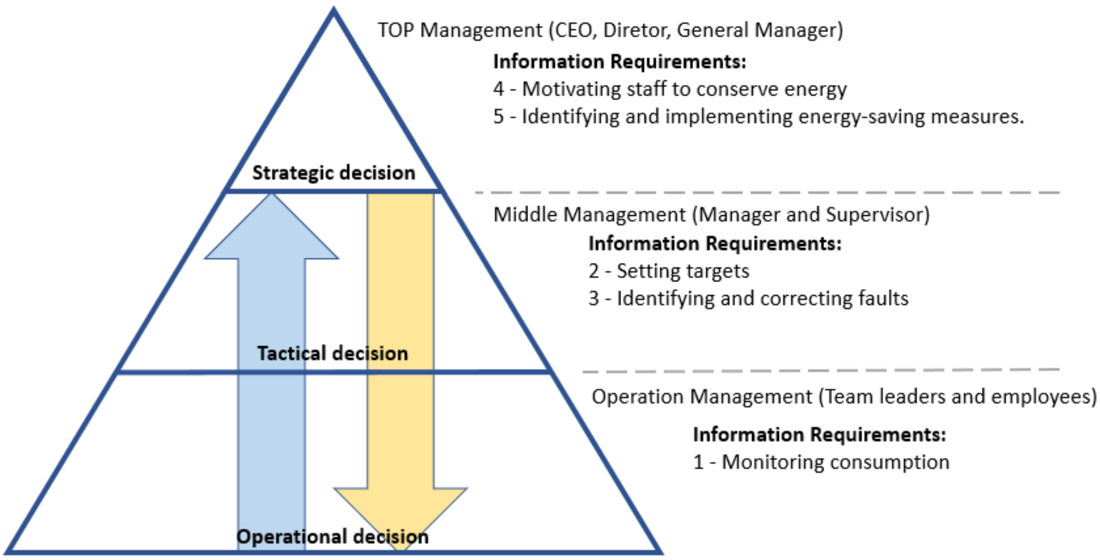

Figure 6 - Bottom-up strategic energy management model [43]

As stated by Anderson J. and Giraldo L [52,53], one method to identify the energy consumers in the process is modelling the process flows. By modelling the process, the elements of the system that consume more energy and materials can be recognized. Once these elements are known, it is possible to start identifying the variables that affect the system.

The first step to develop a process flow is to map the inputs and outputs of energy and mass of a given system, - a system could be an equipment, a work unit or the whole organization, it depends where the boundaries of the system are placed - the difference between inputs and the outputs of every process will outline the energy and mass consumption [54]. The process flow intends to visually identify the energy consumption of each process. Figure 7 displays a schema of a process flow, where it outlined the common interveners in a process flow, inputs and outputs. For simplification, if several processes are in sequence, and the product output that is associated with each process is known, multiple processes could be incorporated into a single model. However, it is necessary to consider the level of aggregation so that the process continues to provide the required information.

It is important to remark that [54] when developing a process flow model, the main challenges occur when one process leads to multiple products and when there is a recycling of energy or material within the system. All these challenges have a direct effect on the measurement of the final consumption. Thus, it is imperative to set simplifications when needed, without compromising the result.

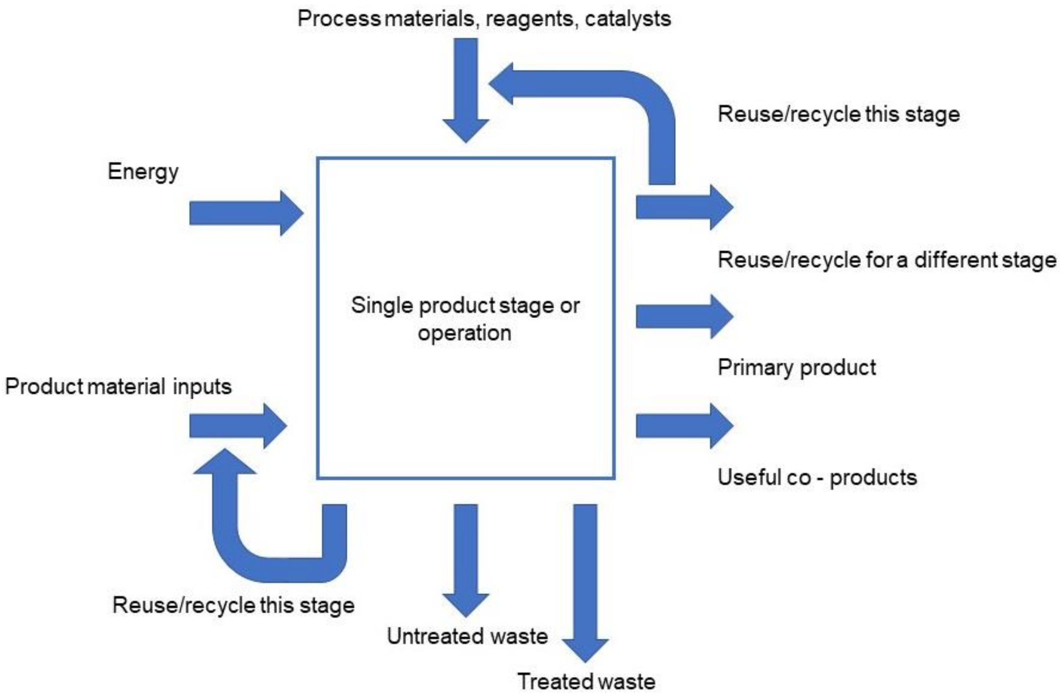

Figure 7 - Schema of a Process Flow taken from Hyman B. at al. (2019)[55]

It is possible to state that the variables outlined by the diagram process flow or rearrangements of these are potentially KPIs since they provide information of the performance of the system [18]; In the next section, three different methods for selecting e-KPIs that uses the flow diagram to identified the most relevant metrics to control and manage energy consumption are presented and compared.

Methods for selecting e-KPIs

In this section, three different methods for selecting e-KPIs for measuring and managing energy consumption are described. Each method is related to a different scale-dimension identified by May G. The first method, equipment analysis, compares the design performance working parameters of equipment/work-unit with the current working conditions. The second method evaluates the energetic performance of a work-unit/section taking into account the energy being used in the processes and the production. Lastly, the exergy method attempts to evaluate the amount of energy and material that it is being consumed under a single metric, providing an efficiency metric of the resources are being used.

These methods were chosen because of the significant improvements they exhibit when applied in manufacturing industries.

2.7.1 Equipment analysis

The equipment analysis method for selecting KPI, described in a 2015 article called *"Equipment performance analysis of a Canadian Kraft mill. Part I: Development of new key performance indicators (KPI)"* by Paris J., states [46] that the design conditions of a process are KPIs because they provide information about how far the work unit/equipment is from its maximum efficiency point – less consumption.

The idea behind the method is that commonly, process integration techniques and optimisation procedures are built on the implicit assumption that the unit operations and equipment are working efficiently, which is not always the case. Before trying to optimise a system, it is crucial that every piece of the system is working as it is intended. Hence, to tackle this challenge, in manufacturing environments, operators need to access quickly if the process/machines are performing as intended and take corrective actions if required. Having this in mind, Paris J. proposed the used of dimensional analysis as a useful tool to map the e-KPI of equipment in a pulp mill for assessing if the working unit is working as intended [46].

Through the application of dimensional analysis in the largest energy consumers, Paris J et al, were able to identidied the e-KPIs that influences the energy performance of the main equipment in a Pulp mill [47]. The application of the proposed e-KPIs on an Eastern Canadian pulp mill identified low performing areas/sectors and improvement projects were proposed having as a foundation the diagnostics suggested by the KPIs. The improvement projects led to significant steam and water savings and improved the overall energy performance of the mill compared to other Canadian Kraft mills – "*The methodology has been applied to an Eastern Canadian Kraft mill and several improvement projects leading to 30% of energy savings are proposed, entailing a low investment cost and a payback of 1.1 a*" - Taken from the article Paris J . However, Paris J. advice to maintain the process performance once the improvement projects are implemented, close monitoring of KPIs should be done. Moreover, a database for optimum operating e-KPIs was developed by the mill over time and correlations between KPIs could be developed in order to understand better and describe the processes performances.

2.7.2 Manufacturing states and energy states

Another methodology for the selection of the e-KPI is the one proposed by May G. [21]. The methodology identifies the amount of energy consumed in the various energy states process and connect them to the respective machine configuration state in order to assess the different process' efficiencies. The recognition of the various process' efficiencies provides specific information on how the energy is being consumed.

The method could be summarize in a 7 step methodology [21]:

1. Definition of the reference production system
2. Identification of different power requirements of the productive resource: the power requirements represent the process' energy states
3. Analysing of manufacturing states as the cause of energy inefficiencies of the productive resource
4. Linking manufacturing states with energy state
5. Building a hierarchical framework of the machine's energy consumption
6. Development of e-KPIs: The e-KPIs generated are general indicators.
7. E -KPI design and management: Once designed the e-KPIs, they need to be managed. It is essential to keep them in a record, according to the minimum valid interval between measures is months.

This methodology is important because the resulting e-KPIs provide valuable information on how and where the energy is being consumed in the process, addressing one of the major gaps identified in the literature [5].

2.7.3 Exergy as a method for choosing e-KPIS

The last method described was proposed by Hernandez A., and it states [56] that by combining energy efficiency and material efficiency under a single metric, manufacturing process could easily asses energy policies and identify potential sources of improvements. Even though Hernandez A. does not classify her method as a way to identify e-KPIs, the method provides a methodology for finding metrics that assess the energy and material performance, which could be in some cases e-KPIs.

As seen in the literature, energy intensity metrics are universally accepted in industry, academia and the policy sphere for assessing energy improvements [44].. Yet one of the disadvantages of energy-intensity metrics is that they only quantify the degree to which energy inputs and energy by-products are used and produced, overlooking the energetic value of material by-products or materials inputs.

A recent study, [57] reviewed the material efficiency (ME) metrics that are used by the manufacturing industry, and it concluded that the metrics do not address the practical aspects of measuring ME in manufacturing firms, more specifically "…how other indicators interact with ME measurements, and how they are connected to the overall goal and strategy of company". To resolve this, academics from different fields developed the concept of exergy: a means of measuring different types of energy and materials used in a single metric. Exergy can be defined as "the maximum theoretical useful work obtained if a system is brought into thermodynamic equilibrium with the environment." [58].

Having this in mind, in 2018 Hernandez A proposed [56] exergy efficiency as a relevant metric for manufacturing managers assess their decisions on how to improve resource efficiency, i.e., energy efficiency and material efficiency. So, when they take the decision, they can considerate the resource interactions across different processes and sectors; reflecting both resource's quality and quantity.

Generally, exergy efficiencies are defined as ratios of resource inputs to resource outputs and can include either energy or materials alone or a combination of the two. Both the numerator and the denominator are measured in joules of exergy, providing a dimensionless metric that ranges between 0 and 1.

Nowadays, there are two types of exergy efficiencies, total and rational. The total exergy efficiency is described as [58] the ratio of total output to total input exergy flows. It reflects the internal exergy losses (irreversibility) in the process and avoids the need to make judgements on the usefulness of the output products. While rational efficiencies [59] distinguish between energy and materials that undergo transformations –consumed – and those that remain unreacted. In chemical reactions, such as in the production of paper's pulp, rational efficiencies are typically denoted as transit exergy efficiencies

Hernandez A. advice [56] that the total exergy efficiency is predominantly appropriate for evaluating the performance of processes that entirely transform all inputs into useful outputs.

In her doctored dissertation Hernandez A. assessed the energy and material performance under exergy efficiency metrics and obtained excellent results "7% of the total exergy input can be saved" – Taken from [56].

The benefits of using exergy metric were identified:

- Exergy allows a better characterisation of energy and material-transforming processes using a single metric. Both energy and mass balances alone do not quantify the upgrade in material quality that is enabled by dissipating high-value fuels into low-value heat.
- It reflects resource quality and gives insight into which material or energy streams are worth recovering.
- Exergy offers an integrated measure of energy and material use, which is dimensionless and can consequently be used to compare efficiencies across industry sectors.

2.7.4 Methods analyses for selecting e-KPI

The abovementioned methods were described as a means to select e-KPIs. They were chosen because they have led to good result when applied in case studies and because they addressed at least one of the industrial needs identified by May G.

Even though they are different methods, they have similarities. The first one is that the resulting e-KPIs are dimensionless ratios which are in accordance with the literature,[42,43] which states that the most common e-KPIs are efficiencies.

The second similarity is that they were developed using a bottom-to-top approach, i.e., they begin by identifying first the energy consumers and then develop the e-KPIs. By using a bottom-up approach, the potential energy savings are restricted from the start because there is a limit, which leads to circumscribed energy management systems

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State of the Art conclusion

To address presented restrictions, in the following section, a framework for selecting e-KPIs will be proposed as a means to easier the selection process

As seen in the literature [37], companies are facing new challenges due to environmental regulation and a shift in customer perching behaviour towards more environmentally friendly products. To address those challenges, they began to create sustainability programs. However, a 2016 report [6] shows that only 2% of the organisation achieve the target of those sustainability programs. The report pointed out as a primary factor that most of the time sustainability metrics and business metrics are not aligned, i.e., sometimes, in an organisation, operators are in a position that they choose between achieving business metric or sustainability metric. This situation could be explained because the statement of the sustainability mission does not consider the business mission. Therefore, it necessary to align both. The report also considers as a critical factor for success the communication of the sustainability goals as well as the metric used to control their achievement.

Currently, the business strategy of an organisation is developed using top-down approach [10]. The most popular tools for that purpose are Hoshin Kanri and BSC. Hoshin Kanri is mainly used to state the mission and annual directresses that an organisation must achieve, while the BSC is a framework that helps to communicate the mission and goals to the employees per company sector and aids in the selection process of the metrics to monitor the achievement of the goals.

To achieve the company's objectives, the statement of the goals and metrics is not enough, as G. May states [35], it is crucial to ensure the cause-effect relationship between goals and KPIs. However, for that purpose, the BSC alone has been proven insufficient. Hence, it is necessary to use other tools to guarantee the interconnection of the goals and metrics. The authors of the BSC proposed [17] the use of an SM framework to visualise how the organisation's goals and metrics are correlated. The SM is a framework that places each objective and metrics according to a category and highlights the interconnection between them through arrows. If there is a goal or metric that is not related to any of the other objectives or mission, it must be reworked.

After guaranteeing that all the objectives and metrics are correlated, the KPI network is created and need to be managed and communicated accordingly to the information they provide to the different hierarchical levels.

During the research process, no study was found that proposed BSC and SMs as a medium for an organisation to develop its sustainability strategy or as a guide for obtaining and managing e-KPIs. Therefore, to overcome the preceding stated limitations and to consider the gaps identified by May G [35], this work will propose adaptations to BSC and SM frameworks to create a sophisticated tool to develop an energy management system for selecting and control e-KPIs. It will be considered manly the management of energy in an organisation due to the value of the energy sources, the environmental impact it has, and the available information.

3. Methodology

In this dissertation, a methodology was developed to ease the development of the organisation's sustainability strategy and selection process of e-KPIs under the same framework. It intends to address some of the gaps and needs in the manufacturing process outlined by May G. [5] in his literature review about e-KPIs. The gaps and needs mainly considered were: few guidelines in the e-KPI selection process, energy management supporting tool undeveloped and the insufficient information that current e-KPIs give on how the energy is consumed

In order to acquire knowledge an understand better the context of energy management, a two-month internship was made at a pulp factory. Here, with the aid and experience of the factory's engineers of the methodology iterated in order to be suited for the energy management field.

Taking into consideration the above-mentioned, it is expected that this method contributes to:

- Use the e-KPIs to express the organisation's strategy
- Align the e-KPI and Business KPI towards the same objective
- Increase the guidelines that help to select e-KPIs

The present methodology will consider that the organisations already know what their sustainability mission is. Therefore, the Hoshin Kanri will be out of the scope.

To simplify the implementation of the adapted framework, the proposed method will preserve the as much as possible the structure of the original BSC and SM. All the adjustments will take into account the ISO 22400, the energy management terminology and the e-KPIs categories.

Furthermore, after selecting the metrics to monitor the goals, the present methodology proposes the use of the ISO22400 framework as a medium to document them as e-KPIs and as a tool to discover the variables that influence them

Hierarchical division

To obtain an e-KPI network according to the company's reality, the presented methodology proposes to begin with the division of the organisation in its hierarchical levels as advised by B. Marrs and D. Parmenter. Figure 8 provides an example of how it can be done.

As is possible to see, the strategic decisions should be of the responsibility of the top management, while the tactical and operational decisions are of the responsibility of middle and operational management. Depending on the company, the information requirements can change at each level. However, it was not found any article that contradicts the scope of the decisions.

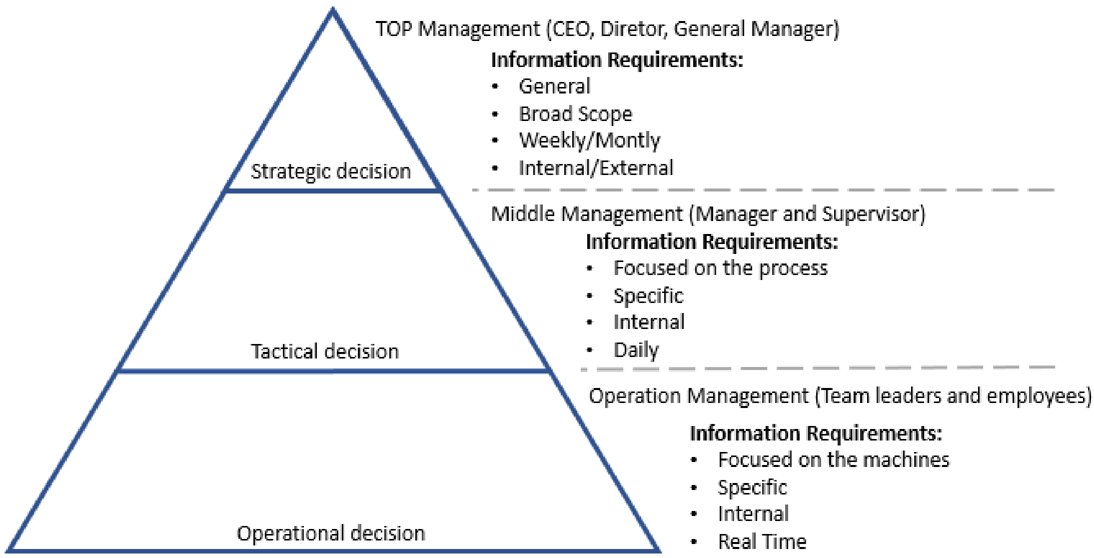

Figure 8 - Information requirements of key decision-making groups

3.1.1 Balanced Scorecard for energy management

The first adaptation made to the original BSC framework was the rewriting of the crucial questions that the objectives and measures should address inside each perspective. Regarding the energy terminology, the original ones were too generic and could lead to purposes that were non-sustainable-related; thus, the need for alteration. The new questions were chosen considering the type of necessities that an organisation face when dealing with an energy management system [60].

Regarding the implementation mechanism, the sequence of steps to deploy the new framework is the same as the original one. First, the company should state a mission that must be achievable. Then, to accomplish the organisation's mission, top management should state objectives for each perspective. Next, for each one of the objectives, managers should propose one metric to measure its progress, set up a target value and implement initiative(s) for reaching that target value. Figure 9 illustrates the macro perspective of the framework.

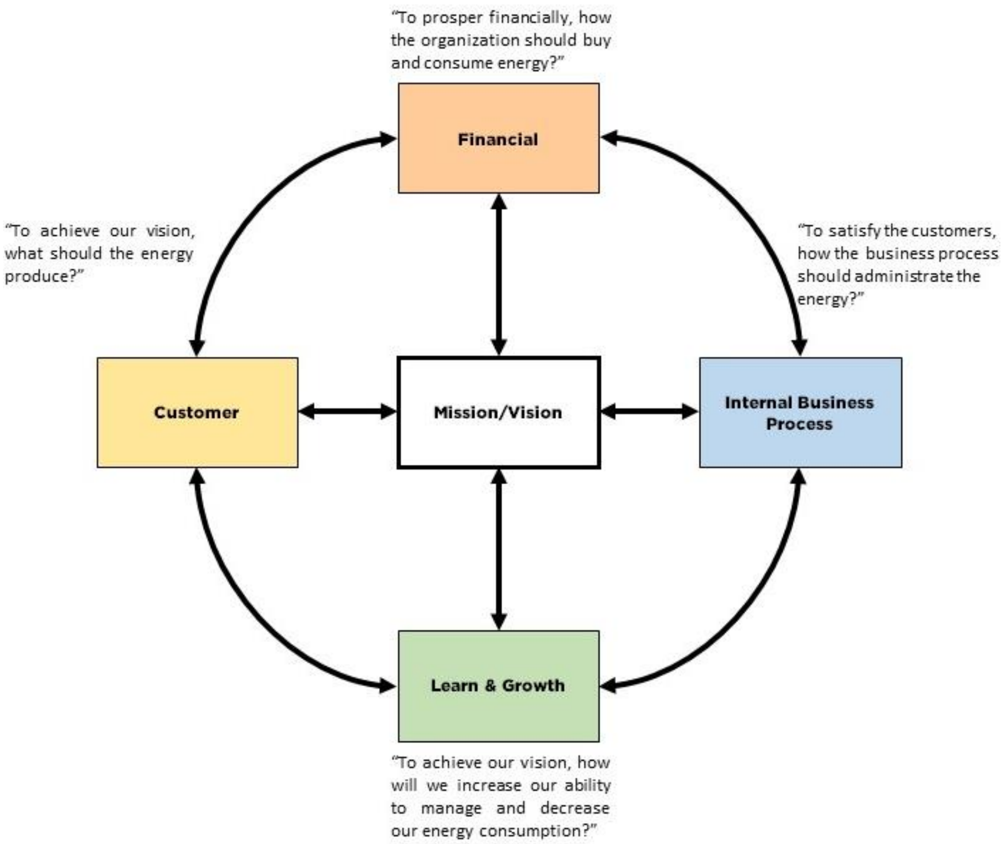

Figure 9 – The macro view of the energy BSC framework.

Figure 10 illustrates the proposed framework for energy management. As it is possible to see the structure and the categories were kept from the original framework, projected by R. Kaplan.

The first substantial modification was the placement of the customer perspective as the foundation of the energy strategy; this adaptation is significant because it was not found in the literature. The reasoning behind the rearrangement of the perspectives was that in any organisation the energy is consumed with the ultimate goal of generating a service or a product; therefore, the specification of the service or product should be the foundation of the strategy. Then, to guarantee them, the energy requirements are managed by the agents of the organisation, such as the employees, the technology and the corporate culture. Next, these agents will apply the energy through an internal process that needed to be financially viable. Finally, the strategic energy mission should respect all the requirements of the perspectives and their connections. Consider the beforementioned, the rearrangement ensures the connection between the e-KPIs and the company KPIs, addressing one of the critical factors to achieve the sustainability goals.

Perspective	Company's Strategic Objectives	Energy Objective	E-KPI	Target	Responsible Person	Initiative
Financial						
Internal Business Process						
Learn & Growth						
Customer						

Figure 10 - Adapted Balanced Scorecard for energy management

It is intended that the BSC for energy management works as a tool to outline the company's energy goals in different organisation's perspective, as well as a channel to ease the selection of the metrics that measure and monitor those goals. Thus, the original column measurement was renamed to e-KPIs instead of metric, this medication has the purpose of reminding the user that the metric is related to energy management and its role in the organisation.

Another significant alteration made to the framework was the addition of the column responsibilities, this addition considered the research made by B. Marrs and the norm IS022400, which sated that for each organisational KPI there must be a responsible person for it [10].

In order to save time and preventing organisation to due redundant work, R. Kaplan advice that after stating the goals and metrics and before filling the rest of the columns of the framework, it is crucial to ensure the cause-effect relationship between goals and KPIs.

To address that purpose, there is a proven tool in the literature that helps to visualise the relationship between the different objectives and their e-KPI, it is called SM and was also proposed by Kaplan and D. Norton when they notice that organisation found difficult to made the connection.

3.1.2 Strategy Map for energy management

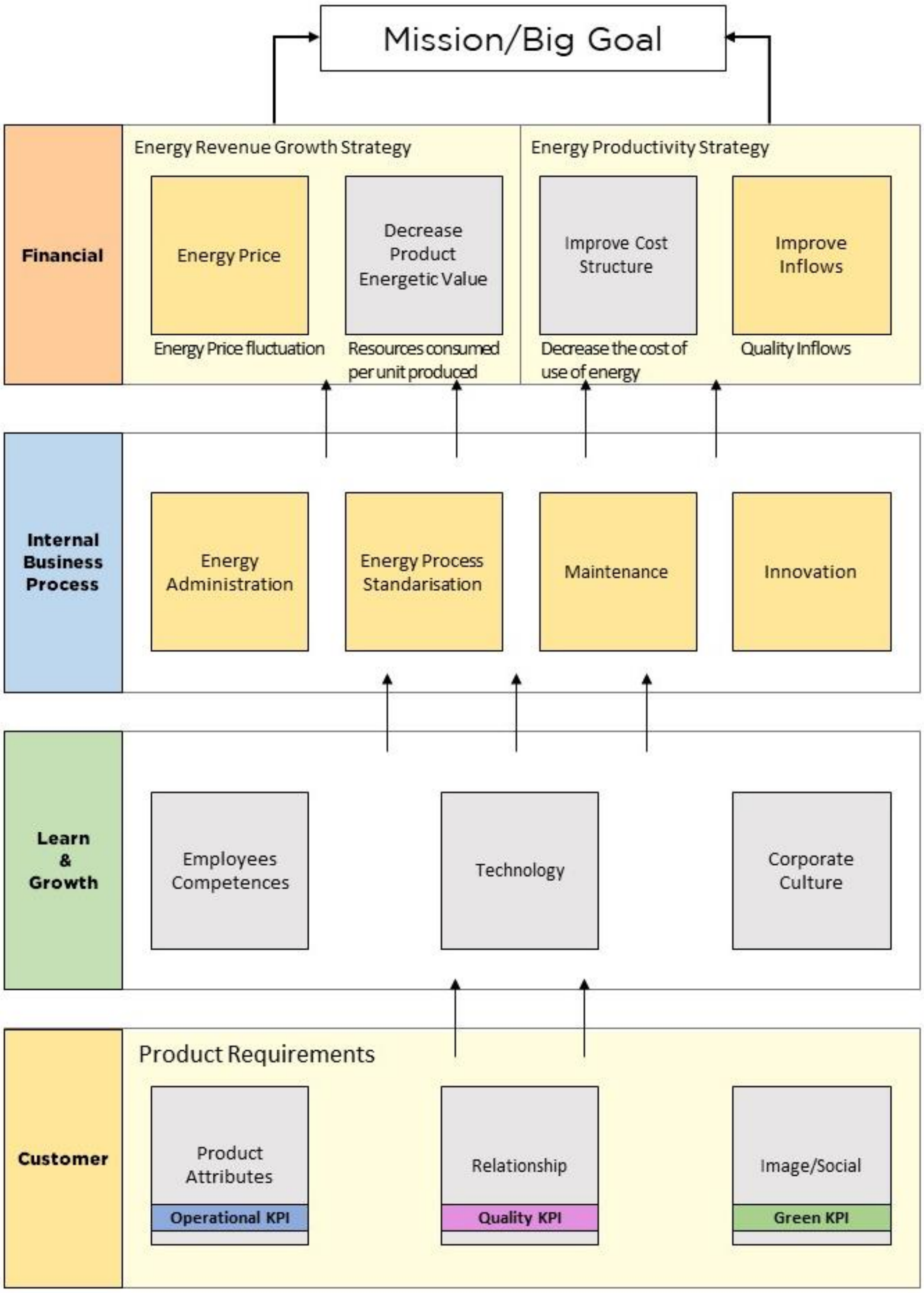

Figure 11 – Adapted Strategy Map for energy management, where the squares represent the possible categories of the organisation's objectives.

As in the BSC, the original SM needed adaptation, because it is considered that the categories identified, where the objectives of each should be placed, did not follow the energy management needs. The above Figure **11** exhibits the new SM framework, the yellow blocks represent the adaptations made, and the greys represent the parts kept from the original frame. The coloured blocks are the requirements of the product or service that the consumption of energy must guarantee.

At the top of the SM framework, the intended organisation's mission should be stated. The initial perspective that the mission is connected to is the financial perspective because, usually, this is the perspective that has more weigh in an organisation. The original divide the perspective into tow groups, one that considers the growth of revenue by increasing the sales and another one that considers the cut of expenses when producing the product. In the new framework, the same group logic was kept; however, they were renamed to be more energy-related, the energy revenue growth efficiency and energy productivity strategy.

The energy revenue growth efficiency group considers objectives that impact financially how the energy is consumed in the organisation. As in the original framework, this group is subdivided into two categories.

- **Energy price:** objectives link to the cost of the energy, i.e., the ones that lead the company to buy the energy at the best price possible or make the organisation less susceptible to price fluctuations.
- **Decrease energetic product value**: objectives that affect the work unit/equipment performance to decrease the energetic product value.

While the energy productivity strategy group considers objectives that could lead to new opportunities for improving financially through the application of new elements or reuse of energy within the system, the production efficiency is also sectioned in two categories as in the original framework.

- **Improvement cost structure**: objectives that reformulate the process of purchasing energy from the grid, for example, the decision of an organisation acquire solar panels to produce solar energy primarily depends on the comparison between the price of energy from the grid and the one from the panel, i.e., the financial cost structure of both.
- **Improvements of the inflows:** objectives that improve the quality of the inputs in the system having in mind long terms paybacks, i.e., the quality of the inflow impact the equipment efficiency and also have influenced its maintenance. Here, objectives that are connected with emission pollutants can be placed. For example, if the company is trying to reduce its carbon emission that objectives should be here.

Since the financial perspective is directly connected to process energy consumption, the following perspective is the internal and business process. In comparison to the original SM, this perspective was the one that suffered more adaptation, all the categories were renamed; however, the number of categories were kept and the logic behind it too. The new categories were named we based on the types of process energy consumption defined in the literature and with the experience of the mentors of this dissertation:

- **Energy administration:** Objectives that increase the control of energy management inside the process. For example: improve energy monitorization.
- **Standardisation:** objectives that attempt to define a baseline for the energy consumption of the process or a baseline for the emission of pollutants.
- **Maintenance**: Objectives that decrease the non-working time or that intend to make the work unit/ equipment to work at their design conditions.
- **Innovation**: Objectives that enable the organisation to improve their energy consumption or reduce the emission of pollutants through inclusion in the process of new elements or technology.

All the business processes are executed by agents of the organisation to produce a product or a service. Therefore, the next perspective in the framework is the learn and growth perspective. All the categories of the classical SM were kept since they accurately summarise all the agents present in an organisation. The objectives of this category should be connected to the operational objectives. If the objectives cannot be linked, they should be replaced with ones that can.

Finally, the foundation is reached; in the new framework, the base is the customer perspective. All the categories identified by R. Kaplan were kept: product attributes, relationship, and image/social. Nevertheless, they were reframed to be under the typical requirements that a service or a product most guarantee. Each of the categories represents a product specification. As a result of this modification, the operational, quality, and green KPIs of the product or services will be the foundation of the strategy, i.e., they will be the first thing to be respected in the organisation.

Finally, after ensuring that there is a continuous connection between the company's objectives to the company's mission, the rest of the BSC framework should be filled, i.e., a responsible person should be connected to each e-KPI, then a target for each metric should be stated as well as initiatives to achieve the target.

3.1.3 E-KPI Structure Framework

After ensuring that all goals and metrics are interrelated, it is necessary to document the metric and attached to a responsible person. For ease the documentation process the ISO 22400 KPI porpose the use of framework as a medium to accurately guarantee that each metrics asure the e-KPI criteria. Therefore, this disseratation propose to use the of the framework for the documentation process. However, a minor adaptation was made to the ISO 22400 framework so it will be in accordance with B. Marr guidelines, the row audience was replaced with the row person responsible. x

Figure 12 exhibits the resulting framework; the adaptation made is highlighted with a yellow colour.

KPI Description	
Content	
Name	
ID	
Description	
Scope	
Formula	
Unit of Measure	
Range	
Trend	
Context	
Timing	
Responsible person	
Production methodology	
Effect model diagram	
Notes	

x

Figure 12 - Adapted E-KPI Framework Structure

A crucial factor of the ISO 22400 e-KPI structure framework is the development of an effect model diagram for the e-KPI in order to understand which variables have a direct and indirect influence on it. Figure 13 illustrates an effect model example.

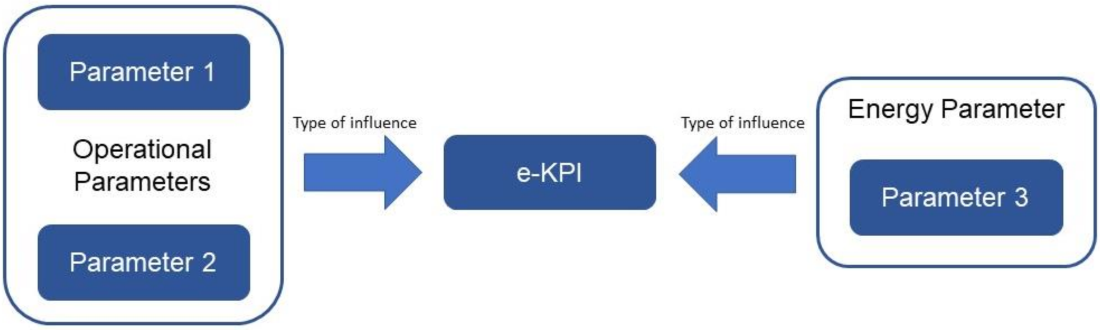

Figure 13 - Effect Model Diagram

For the effect model diagram being in accordance with proposed BSC framework, it is advisable to use the name the related variables considering the different types of areas of the company. This will increase the cause-effect visualisation of the KPI result.

3.1.4 E-KPI network ehibition

After identifying the network e-KPIs and the variales influence them, it is necessary to exhibit the network in a manner that the decision-maker can appreciate how the network is articulated. Following the guidelines of B. Marrs and D. Parmenter, one way to do it is by highlighting the E-KPIs according to the hierarchical levels. Figure 14 is a proposal of how it can be done.

As it is possible to see in the example, there are two kinds of metrics that integrate a KPI network, KPIs and variables. In this methodology, in each hierarchical level there must be an e-KPIs; However, the display of variables that influence is a choice of the person that will assess the information of the network. For readable purposes, when placed, the variables should be ner to the e-KPI that influence so the decision-maker can quickly gather the information needed.

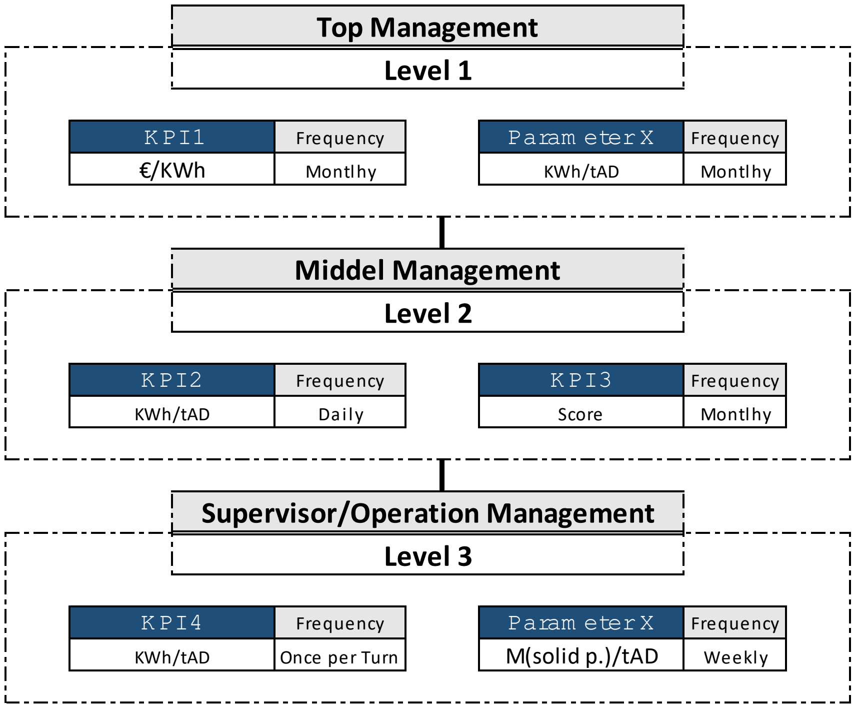

Figure 14 – Example of the exhibition of a KPI Network

3.1.5 Implementation workflow

In order to ease the implementation of the present methodology, a workflow diagram of its application was summarized in Figure 15.

Figure 15 – Methodology application workflow diagram

4. Field Work

Organisation Description

In order to test the proposed methodology and expose its flaws and opportunities, it was implemented in a real organisation - The Navigator Company – with the ultimate goal of accomplish an e-KPI network for energy management. The Navigator Company is an integrated forest producer, whose end products are pulp & paper, tissue, and energy. In fact, the company's products account for approximately 1% of national GDP, and near 6% Portuguese containerized cargo. The end destination of the company products is approximately 130 countries in five continents, with emphasis on Europe and the USA. Currently, the company's mill total annual production capacity is near to 1.6 million tons of paper, 1.5 million tons of pulp each year, 130 thousand of Tissue and 2.5 TWh of electricity per annum.

Regarding energy, the Navigator Company is also a leading operator in the biomass energy sector:

- More than 50% of all power generated in Portugal from biomass, a renewable source of energy, is produced by The Navigator Company.
- The Company generates 5% of all electricity in Portugal.

The production of the company is distributed in four mills, Vila Nova de Rodão, Cacia, Figueira da Foz and Setúbal. This dissertation will have as scope the pulp mill in Setúbal.

Since the organisation is too large to be addressed in a single dissertation, the focus of this work is the pulp production. The pulp mill is a fascinating venue to test the proposed methodology because it is a continuous process and covers different types of consumption. Furthermore, since all the pulp production is an energy-intensive process, any improvement in the energy management field will have a significant impact.

All the company's pulp mills use the Kraft process to produce pulp. As illustrated in Figure 16, the Kraft process consists of two essential parts: a paper line and a recovery loop. The paper line is formed of four departments: woodyard, digesting, screening, and bleaching. While, the chemical recovery loop consists of three central departments: the evaporation, the steam plant, and the causticizing.

To precisely understand the process and the energy consumption in it, a two weeks internship was made on the venue in Setúbal, two days in each part of the process. The internship had as a mentor the energy manager of the mill to explain the energy necessities of the production.

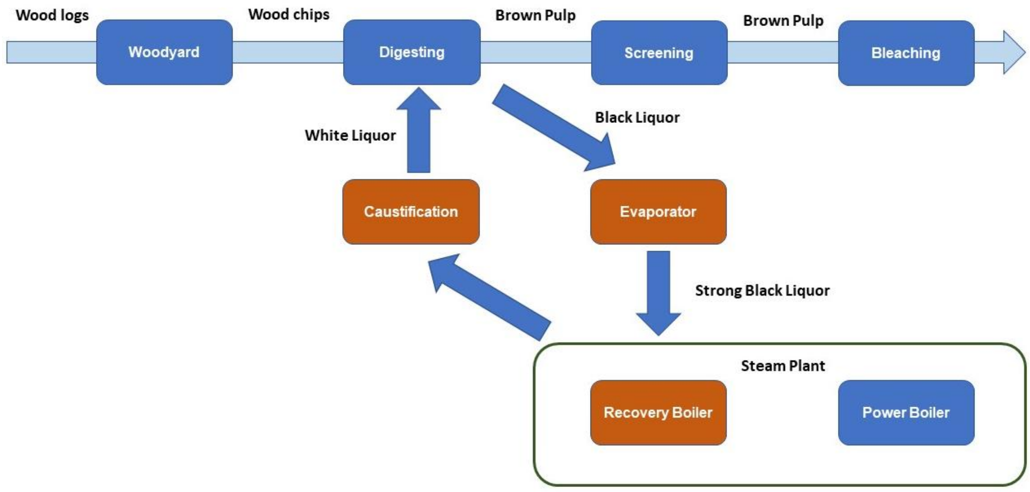

Figure 16 - Simplified Kraft Process [42]

Pulping Process Description

4.2.1 Paper Line Departments

The paper line departments are responsible to transform the raw material, chipwoods, into the final product, in this case pulp. The process of manufacturing pulp begins with the production of the wood chips from wood logs. Wood chips are small sized pieces relatively uniform in size and free of bark.

4.2.1.1 Woodyard

Currently, the Setubal's woodyard has three production lines to transform logs into wood chips Line 1 is only allocated for debarked logs, and line 2 and line 3 for logs that need to be debarked. The lines that treat logs with bark consumes more energy since more machinery is necessary for pealing the logs, as expected.

The process of obtaining chips from wood logs begins with the reception of the logs in a conveyor belt, one per line, that aligns them in a horizontal disposition, then one by one fall in a conveyor network that carries them out through the process. If the logs have bark – line 2 and line 3 - they must pass through 4 processes: scraping, pealing, cleaning, and chipping. While, if they are debarked, they skip the process of scraping and pealing.

The scraper creates small holes along the logs' bark that facilitate the debarking. The bark is torn at the log-peeler. Then, the logs are washed with tap water to take off any sand, rocks or bark attached to them that could damage the machines or lower the efficiency of the digestion process.

Finally, the chipping machine transforms the logs into chips with uniform size, the wood chips that do not have the predetermined sizes are reintroduced in the chipping machine. The wood chips produced by all lines are then stored in a storing pile.

During the visits of the venue, it was observed that the production was measured by the size of the woodchip and that the system stopped due to bark interlocking more than the operators expected, which provoked an energy consumption peak since there were more motors involved in the restart process.

4.2.1.2 Digestion process

The digestion process begins with the reception of the wood chips in the silo. Then, chips are fed into a steaming vessel where they are exposed to steam to enlarge the wood's pores. Then, white liquor is added - this liquor is the primary substance in the pulping process because it enables the separation of the lignin from the cellulose. Next, the mixture is introduced at the top of the digester and slowly flows downwards at 10 bars. During the movement, heat exchangers heat the white liquor - now called cooking liquor - extracted from the digester at two stages (upper and lower) to maintain an appropriate delignification temperature in the vessel and permit a proper recirculation of the cooking liquor. The high temperature catalyses the chemical reaction of the molecular break down of lignin due to the alkaline reagents. The reaction's products are soluble in the cooking liquor, which makes it gain a black colour. The resulting products of this process are brown pulp and black liquor.

To promote circular efficiency, the black liquors go to a flash tank to be retransformed into white liquor at the recovery loop process. And the brown pulp follows to the screening process.

Before the pulp enters the screening process, there is a washing stage, where the brown pulp is washed in contra current to extract as much sodium as possible before being stored in a buffer tank.

4.2.1.3 Screening

After been stored, the brown pulp is then fed to a screening process which goal is to remove the dissolved solids (DS) and uncooked pieces of wood, called knots, from the brown pulp. The equipment used in this department are screeners and knotters [61]. The maximum efficiency in this department is required because any inefficient could cause an increase in operating costs in the bleaching and the evaporation department. [62].

At the Setúbal venue, there are four screening stages. The output of the first is fed to the second until the fourth screening machine is reached. A thumb rule for the efficiency of this process is that 40% of the brown pulp entering the process is wasted matter due to uncooked knots in the wood and debris. All the screened pulp is stored in a buffer before going to the bleaching process.

4.2.1.4 Bleaching

The objective of the bleaching process is to extend the cooking process and improve the proprieties of the pulp, such as whiteness, cleanliness, and chemical pureness. Due to financial and environmental reasons, this process must operate with minimal chemical cost and environmental impact. [63]

By recurring to chemicals, the process intends to remove the residual lignin in the pulp because they confer it a brown colour. Therefore, to achieve the required proprieties, it uses five chemical towers. Each tower is designated accordingly to the chemical used. So, the letter D that stands for Chlorine Dioxide, O2 stage is mentioned as O for oxygen delignification, NaOH is referred to as E for caustic Extraction, and H2O2 is denoted with the letter P for Peroxide delignification. The bleaching sequence is D0EOPD1 [46]. The final result of the process is a final pulp's whiteness is equal or superior to 90º ISO, impose by commercial reasons.

After achieving the whiteness requirements, the pulp is ready to be sent to a paper machine to be converted to paper.

4.2.2 Chemical Recovery Loop

4.2.2.1 Evaporation

The black liquor extracted from the digestor department – called weak black liquor – enters the evaporation department to increase its concentration of dissolved solids to about 70% to improve his calorific power. For this purpose, there are two main sections, evaporation lines - line 2 and 3 -, and the super evaporator. In the evaporation lines, the contaminants and unwanted substances are removed from the black liquor. The difference between the evaporation lines is the type of heat exchanger involved. Line 3 is more recent and holds higher production capacity, it utilizes tubular and laminar heat exchangers, while line 2 only uses the tubular ones. The result of both processes is black liquor with 30% dissolved solids. At the final stage, the black liquor enters he super evaporator where reaches the desired concentration – the black liquor is now referred a strong black liquor.

For logistics reasons, the produced liquor is stored in buffers tanks that were always full at the time of the research, which can indicate a possible bottleneck for the production line and a source of waste energy.

4.2.2.2 Recuperation Boiler

Before entering the recuperation boiler, the strong black liquor is mixed with "fresh" sulphite to compensate any Ph loses within the digestor department, indispensable for the Kraft process.

In the recuperation boiler, the liquor is burned with pre-heated air. From this combustion result two products, hot gases and a liquid substance rich in sodium sulphide designated as a smelt. The hot gases pass through a treatment process where they are filtered by four eco-filters, preventing that any pollutants go to the atmosphere and recuperating some sulphite. While, within the recuperation department, the smelt is mixed with weak white liquor. The resulting mixture is designated as green liquor because it gains a green colour; this mixture is the raw material for the caustification process.

The heat originated from the combustion process is used for generating high-pressure steam.

4.2.2.3 Caustification

The stemming green liquor from the recuperation boiler needs to be filtered because of impurities and solid pieces that it may contain - called drags. Before being removed from the system, the drags are densified and squeeze to harness any green liquor that they may have.

The resulting clean green liquor proceeds to an eraser tank where it is added lime. The lime removes the green colour of the liquor, making it transparent - white liquor. The resulting white liquor is then stored in three unevenness storing tanks. Thought the action of gravity in the first and second tank, only white liquor is stored. However, the third tank contains white liquor and lime milk. Since the lime milk contains a considerable amount of white liquor, the mixture moves to a hose pressurizer to squeeze the remaining white liquor. The resulting mud from the pressurizer is rich in lime, so it is densified and baked to regain lime. Then, the lime returns to the digesting process, closing the caustification cycle

Actual Navigator e-KPI Network

Now that the process is known, it is possible to dissect the current KPI network that the Navigator Company uses to manage its energy consumption and deploy its energy strategy. As it is possible to see in Figure 17**Error! Reference source not found.** that the company only use one type of e-KPI (specific energy consumption), which according to the literature could lead to limited energy management systems.

Since the current KPI network only gives information related to how much energy is consumed in a given department or process, it can be said that the network utilised by the company is the equivalent of a resulting financial board because the network's e-KPIs have the same proprieties of the KRI outlined by R. Parmenter, i.e., the network gives information about aggregated result not giving information on how does results are obtain.

Regarding how the KPI network was structures, the hierarchical division was classified considering the more significant energy consumers in the process and its physical relationship. However, the frequency of measurement attributed to each level do not seem to have been made considering the needs of each department, but instead, it seems to be of the type 'one fits all'.

The current situation exhibits that for the company benefit in its fullness the KPI usefulness, the KPI network needs to the provided more information on how energy is consumed and why it is consumed in order to facilitate the decision-making process. Also, to be in accordance to the KPI theory, the network must be clearly connected to the strategy of the company.

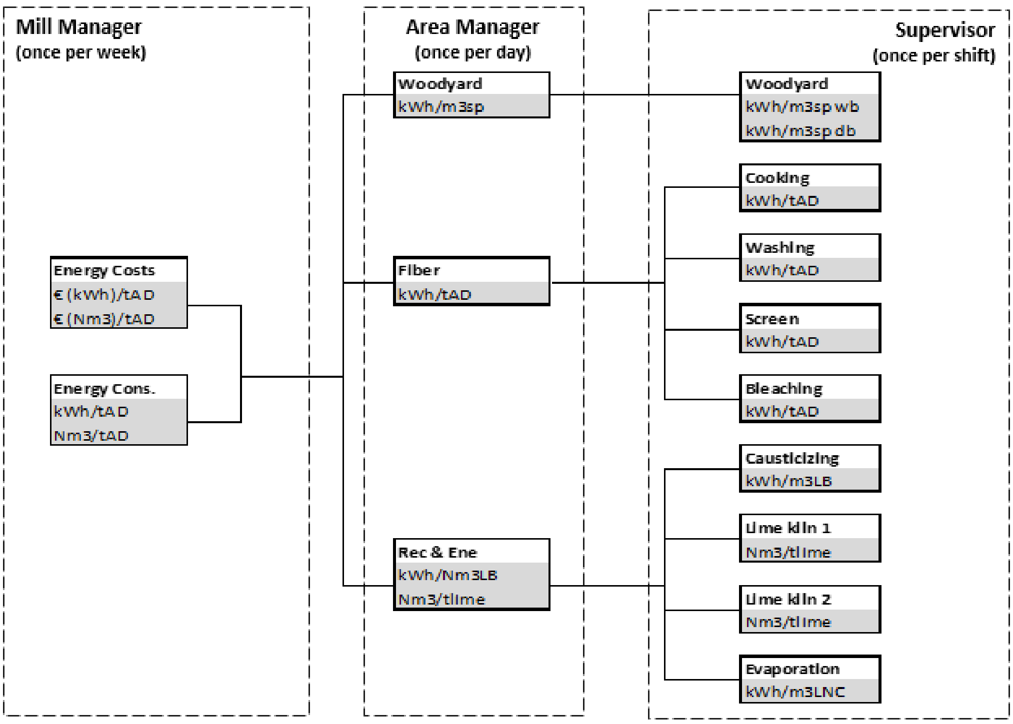

Figure 17 - Current energy KPI network of the Navigator Company

Implementing the Methodology

Considering the before mentioned, with this methodology it is intended to develop a KPI network for the Setúbal industrial complex pulp mill. During the intership it was possible to outline the different hierarchical levels and their information requirements to ensure that the outcome of the methodology responds to the mill's necessities. Figure 18 exhibits the three different hierarchical levels and the required information in each one of them

4.4.1 Organisational hierarchical division

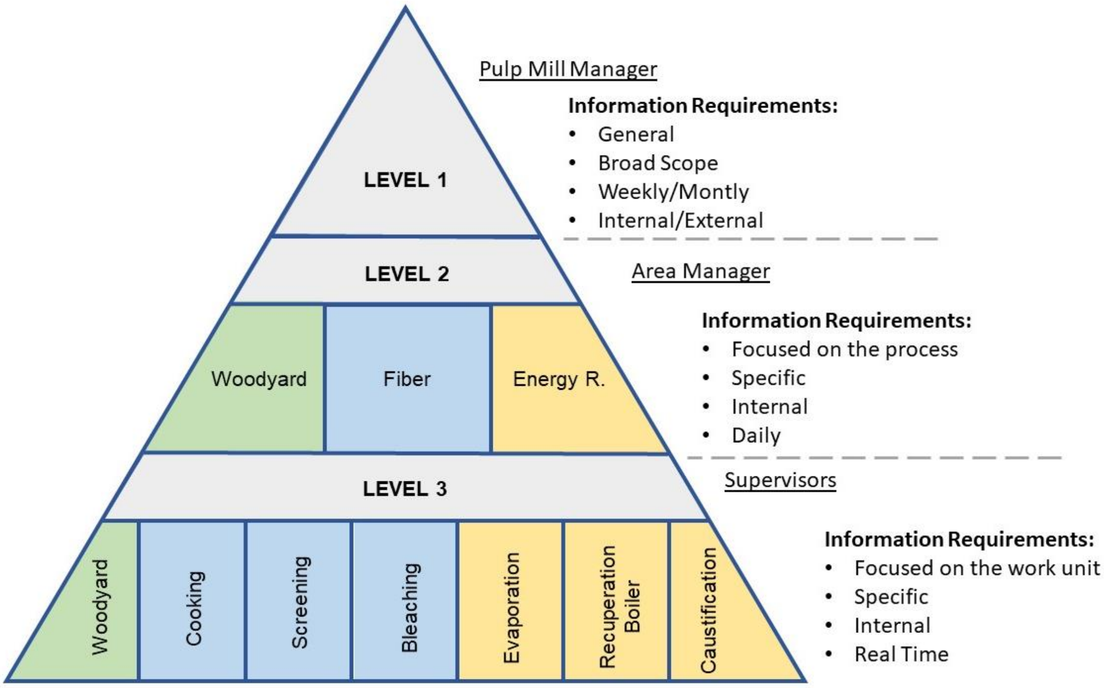

Figure 18 – Organisational pyramid of the pulp mill process

The pulping process was divided into three hierarchical levels due to the company's organisational diagram, the various stages of the process, and the types of decisions made in each level. In this context, level 1 (energy mill manager) considers the development and implementation of the company's strategic energy decision. Here, the pulping process is perceived as a whole, and the information received must be aggregated. Level 2 (Area manager) is divided into three different business areas, woodyard, fibre and energy recuperation, because each operational area is physically separated from one another and because they produce different products. The information in this level must be specific of the performance area, summarising the process performance. Lastly, level 3 is sub-divided in all the working units that compose the business area; the division was made considering all the major energy consumers (mainly equipment) and the various stages of the pulp. In the last level, the information must be acquired in real-time, so if there is any deviation from the target, the workers can correct it immediately.

4.4.2 Organisational BSC for energy management

After the identification of all the different hierarchical levels, the company provides the strategical objectives of the company that were placed into the framework. Then, with the help of the pulp energy manager, the company's energy objectives needed to achieve where stated. Even though all the company's objectives were equally important, the one that had more weight in the energy management department was the mission decrease in the energy consumption in the pulp mill until 2021, while reducing the production cost and increasing the production rate.

With this information, it was possible to fill the BSC framework for energy management, associating each objective with a certain organizational perspective. As stated by R. Kaplan, whenever an objective was placed in the framework diagram, a measurement was connected to it. Figure 19 exhibit the completed BSC framework.

Perspective	Company's Strategic Objectives	Sustainability Objective	E-KPI
Financial	• Increase in the pulp production rate until 2021 • Decrease the number of non-planning stops • Introduction of social and environmental sustainability elements the business model • Increase the motivation levels among employees • All departments should be guided by principles of transparency, ethics and respect when dealing with each other and with other • Increase the contribution of employees in the innovation process	Reduce the cost of energy	*€/KWh*
		Improve the energy efficiency of the equipment	*KWh/tAD*
		Increase the energy from new sources	$\%E$
		Increase the profitability of the inflows	$M_{woodchip}/Tad$
Internal Business Process		Reduce process energy waste	E_{useful}/E_{total}
		Standardize the minimum energy consumption	$\%E_{save\ due\ to\ improv.}$
		Increase the monitorization and control of energy in the process	*Score*
		Modernize the pulp making process	*Time to approval*
Learn & Growth		Enhancement employee energy management knowledge	*Return to Investment*
		Take maximum advantage of the energy management tools	*Frequency of use of E-tools*
		Build a strong awareness towards energy consumption	*Survey*
Customer		Excellent Pulp	*Operational and Quality KPIs*
		Environmentally friendly pulp	*Green KPIs*

Figure 19 - Completed BSC framework for energy management done in colaboration with the energy mill manager (level 1)

Whenever an objective was stated an e-KPI was attributed to it. These metrics were chosen by the person who will be responsible for its achievement while considering the available literature [19]; the process selection worked as follows: for every objective, three possible metrics were identified, then the one that outlined the information that helped the most the decision-making process was kept in the framework.

The first perspective filled was the customer's. Here, the objectives follow the requirements that the outcome pulp must guarantee; these requirements are achieved through the accomplishment of the operational, quality, and green KPIs target values, imposed by the final customer – another factory section or an external customer. Since the end product can change depending on the costumer, there were not specified in Figure 19.

The second perspective filled was the learn and growth perspective. The perspective's objectives were stated considering the human resource policies of the Navigator Company and the company's new investment in energy management tools. The first goal identified was the enhancement of the employee's energy management knowledge, which intends to assess the profitability of the current training given to the employees; therefore, the metric chosen was training return on investment. The second goal intends to analyse if the new energy tools are part of the work day of the employees; hence, a frequency utilisation metric was attributed to the goal. Finally, the third goal intends to assess if the company's employees are aware of energy management needs. Since this objective aims to measure the culture of the company, the metric chosen was a company's energy management survey.

The third perspective filled was the internal and business process. The goals in this perspective propose to assess how energy is consumed in the pulping process. The first goal, increase the monitorization and control of energy in the process, intends to evaluate the monitorisation and control capacity of the process; therefore, the metric chosen was the software sustainability index, which evaluates through a score process how much a structure is adequate for energy management. The second goal, standardize the minimum energy consumption, intends to set a benchmarketing goal of the best energy production scenario and assess how far the process is from the baseline; the metric selected for this purpose was the percentage of energy due to improvement, which assesses in a percentage base how far the process performance is from a selected baseline. The third goal, reduce process energy waste, tries to evaluate how the energy is consumed in the process, i.e., which amount of energy is using profitable; the metric chosen for this purpose was the lean energy metric, which is a ratio between the profitable energy and the total energy consumed. The last process' goal, modernise the pulp making process, intends to asses if the proposed projects for innovation are implemented; the metric chosen for this purpose was the time to implementation which assesses how much time it takes to a project being implemented since its proposition.

To conclude, the last perspective filled was the financial one. In this perspective, the objectives consider the process' financial viability and the amount of energy consumed. The first goal, reduce the cost of energy, tries to assess the energy cost of the process; the metric chosen was the price of a KWh. The second goal, improve the energy efficiency of the equipment, intends to decrease the energetic value per TAD of pulp made; the metric selected was the specific energy consumption of a TAD of pulp. The third goal, increase the energy from new sources, tries to promote the creation of a mechanism that decreases the energy consumed from the grid; the metric chosen was the percentage of energy saved due to the usage of these sources. The last goal, increase the profitability of the inflows, intends to find new ways for making the inflows more profitable, such as increasing the production by changing the types of woodchip; the metric selected is the resource efficiency.

After selecting the metric for each objective and before stating targets for the metrics, the SM framework for energy management was filled with the objectives and metrics identified to ensure their interconnection. Figure 20 displays the completed framework.

4.4.3 Organisational SM for energy management

After placing the objectives and metrics according to their position in the SM framework, the cause-effect links were identified by the author of this thesis with support and knowledge of the energy pulp mill manager.

Starting from the bottom, in the customer's perspective, the operational and quality KPIs are linked to the employee's competence and company's technology because those are the primary agents that secure them, while the green KPIs are mainly guaranteed by the corporate culture and process' technology.

Inside the learn and growth perspective, the first objective, the increment of the employee's knowledge, has a direct impact on how the energy is monitored and managed as well as how the energy is used in the process; likewise, with more knowledge, the employees can find new ways to modernise the process. Prevailing in the same perspective, by taking maximum advantage of the available technology the easier it is to manage and control the energy consumption in the process, while also increasing the possibility of modernising the process without introducing new elements. Finally, the last goal, build a strong awareness towards energy consumption, enables the organisation to work towards finding new ways to modernise the pulping process, reduces the energy waste and standardises the energy consumption to minimum levels.

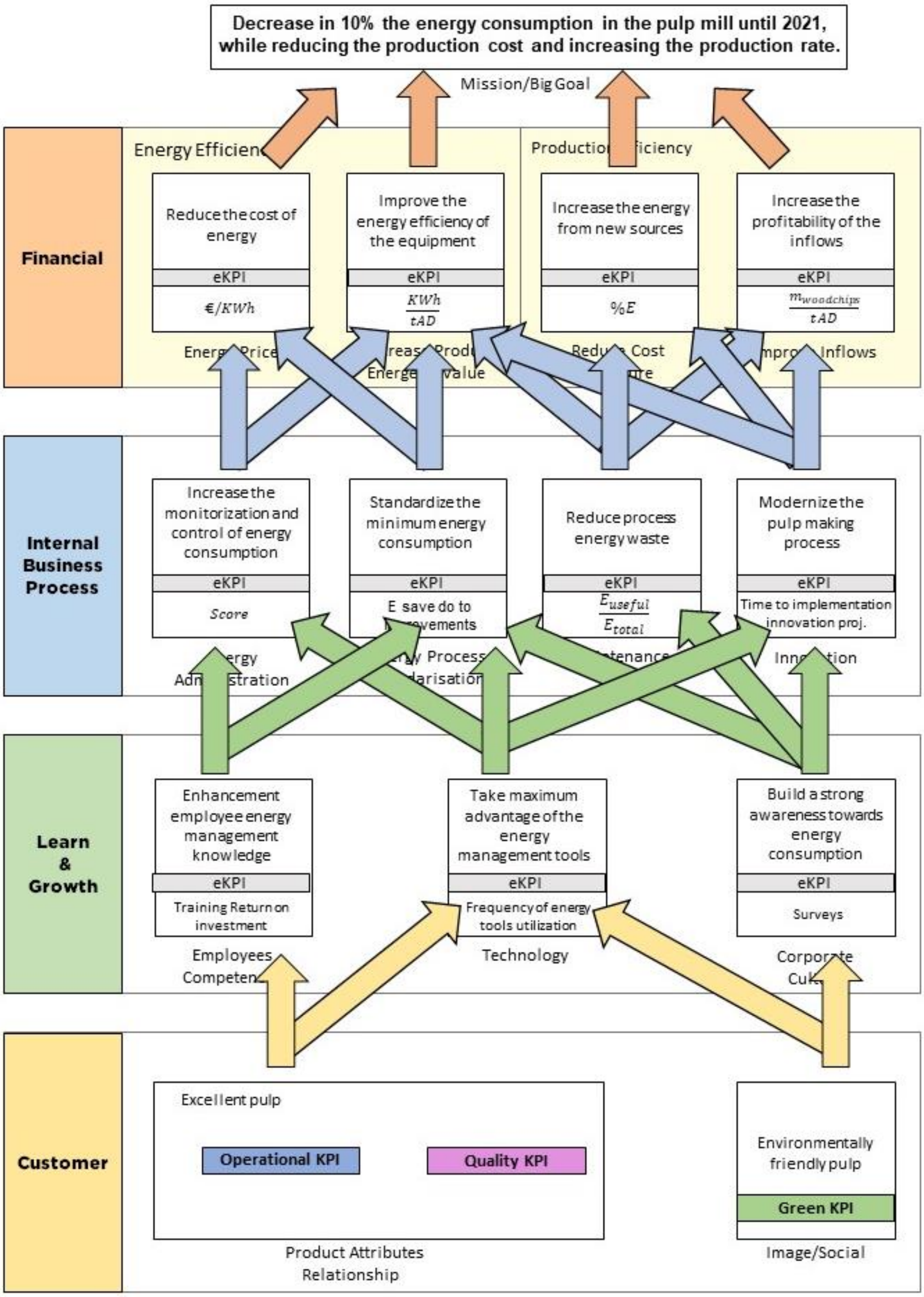

Figure 20 - Completed SM framework for energy management

Halfway to the top, in the internal and business process perspective, the first goal, increase the monitorization and control, has a direct impact on how the energy is consumed in the process and the company's energy bill; similarly, the second goal, standardise the minimum energy consumption, has the same impact. Regarding the third goal, reduce the energy waste, the energy efficiency and material profitability of the process will increase, as well as the possibility of finding new sources of energy. Lastly, through the modernisation of the pulping process, the efficiency of the process could be improved, new sources of energy could be included, and new ways to make the materials inflows profitable could be discovered.

Finally, reaching the top of the framework and inside the financial perspective, the first goal, reduce the cost of energy, guides the organisation to achieve the financial viability of the energy mission. The second goal, improve the energy efficiency of the equipment, is directly connected to the consumption reduction part of the organisation's mission. The third goal, increase the energy from new sources, enables the company to reduce the grid consumption, and finds new ways to feed the process. Lastly, increase the profitability of the inflows, helps the organisation achieve its mission by increasing the earns from the inputs, making the process more efficient.

4.4.4 Documentation of the e-KPIs through the ISO22400 framework

After ensuring that all the objectives and metrics were interconnected, the ISO 22400 framework for stating the e-KPIs was used for each of the proposed metrics. Figure 21 displays an example of one of the selected metrics.

E-KPI Description	
Content	
Name	Specific Energy Consumption
ID	1002
Description	Specific energy consumption is the ratio between all the energy consumed in a production cycle and the produced quantity (PQ)
Scope	Pulp Mill
Formula	e = E/PQ e: unit energy consumption of an equipment E: Total energy consume in a production cycle
Unit of Measure	KWh/TaD
Range	Min: 0 Kwh/tAD Max: product specific
Trend	The lower,the better
Context	
Timing	Weekly
Responsible person	Pulp Manager
Production methodology	Continuous
Effect model diagram	See Figure 18
Notes	Energy consumption is an important factor impacting the production costs and company profits. National

Figure 21 - ISO 22400 Framework for Specific energy consumption e-KPI

The example above considers the metric for the objective of the financial perspective - improve the energy efficiency of the equipment. The first step to fill the framework is to state the metrics content information: name, ID, description, formula, unit of measure, range and trend. After that, it is necessary to consider the KPI working context, i.e., what the metric tries to evaluate. In this case, since the energy pulp manager will only make decisions based on the weekly specific energy consumption of the mill, the frequency of measurement attributed to the e-KPI was on a week basis. Moreover, because the energy pulp manager is the utmost interested person assessing the metric, he will be the person responsible for it. The next step is to create an effect diagram that presents the variables that affect the metric; Figure 22 exhibits the effect diagram for the specific energy consumption, and it is possible to see that the metric is an aggregated result of the same variable in sub-hierarchical levels. Therefore, the same metric will be considered as an e-KPI in the lower levels. The effect diagram is crucial for finding e-KPI in the lower hierarchical levels of the organisation. Finally, it is possible to add a note that highlights the importance of the metrics.

It is important to remark that only after each of the metrics is exhibited under the ISO2240 framework are they labelled e-KPIs because the framework ensures that the metrics fill all the required criteria to be considered e-KPIs.

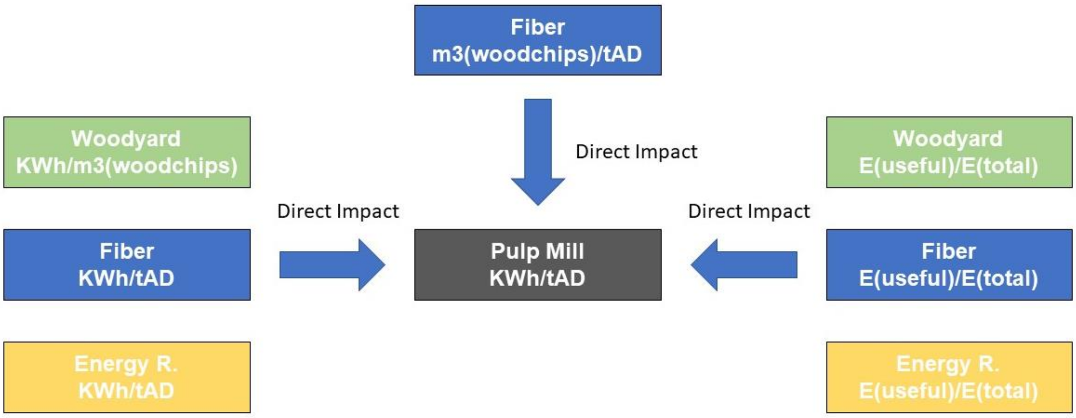

Figure 22 - Effect Diagram Specific Energy Consumption (Level 1)

As can be seen in the e-KPIs effect diagram, the same e-KPI can be found in sub-hierarchical levels, depending on the information requirements of the decision maker, i.e., the information aggregation level. Considering this, and with the aid of the energy pulp manager, the unfolding of this e-KPIs was summarised in Figure 24.

4.4.5 E-KPI network for energy management

With the information provided by Figure 23 it is possible to begin to construct the KPI Network. However, due to the complexity of the pulping process, the KPI network was only developed for the fiber department as Figure 24 exhibits

E-KPIs	Mill Manager	Area Manager	Woodyard	Fiber	Energy Rec.	Supervisor							
							Fiber			Energy Rec.			
						Woodyard	Cooking	Screening	Bleaching	Causticizing	Lime Kiln 1	Lime Kiln 2	Evaporation
Cost of energy	X												
Specific energy consumption	X		X	X	X	X	X	X	X	X	X	X	X
Percentage of consumption from new energy sources	X												
Material efficiency	X			X	X		X			X			X
Software sustainability index	X												
Energy saved due to conservation & efficiency improvements	X		X	X	X								
Lean Energy	X		X	X	X								
Process innovation	X		X	X	X								
Training Return on investment	X												
Employee online engagement level	X		X	X	X								
Energy saving Culture	X		X	X	X								
Operational KPI	X		X	X	X	X	X	X	X	X	X	X	X
Quality KPI	X		X	X	X	X	X	X	X	X	X	X	X
Green KPI	X		X	X	X	X	X	X	X	X	X	X	X

Figure 23 - e-KPI for energy management

4.4.6 E-KPI network for energy management for the fiber area

Figure 24 exhibits the KPI Network developed for the fiber area; the level 1 indicators are the top management e-KPIs, while level 2 and 3 are the middle management and operational e-KPIs, respectively. As shown above, some KPIs from the top do not unfold to the lower hierarchical levels; because the information that they provided is out of the scope of the area managers, i.e., they do not need the information to make decisions.

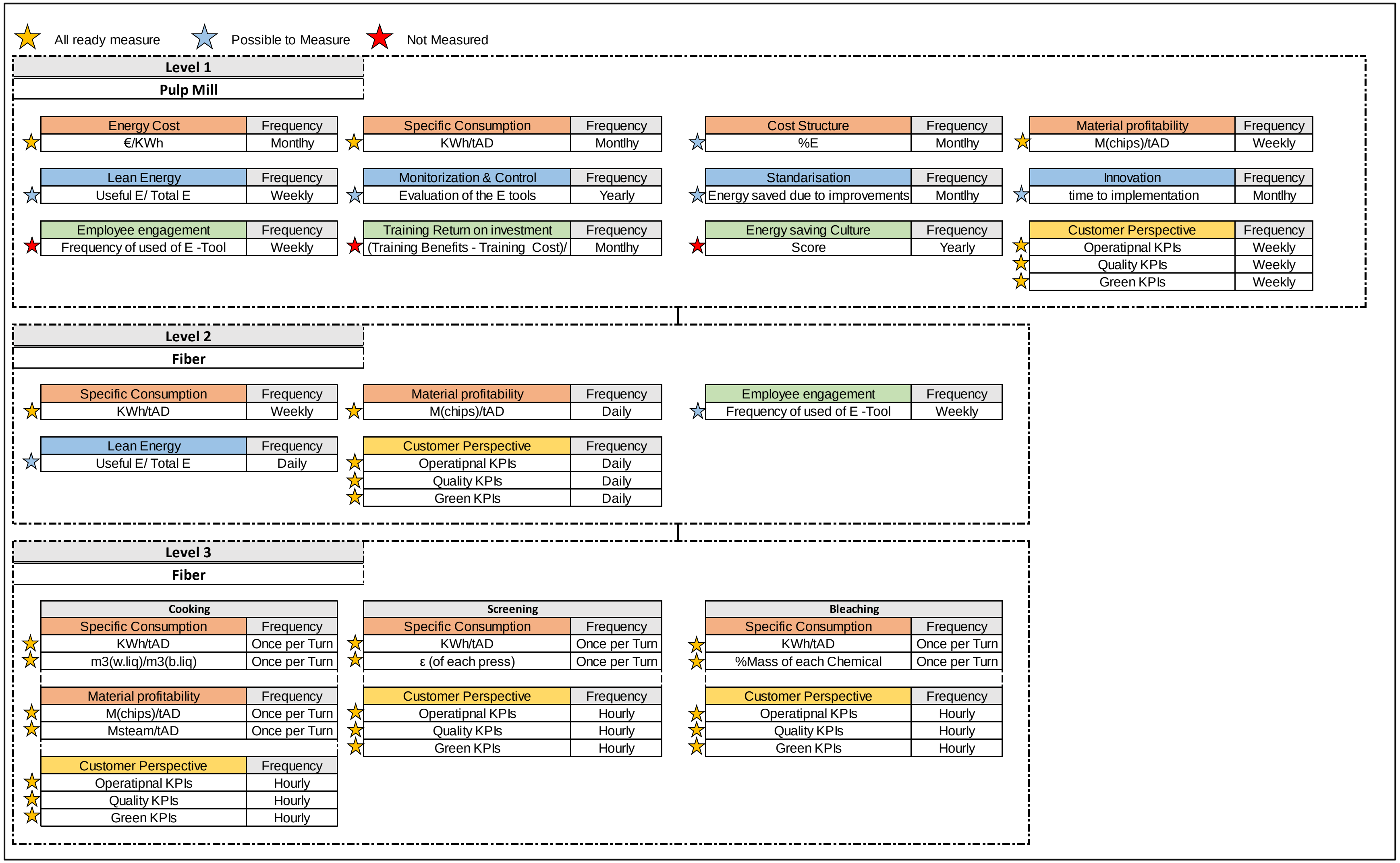

Figure 24 – Part of the KPI Network considering the Fiber Area

4.4.7 Organisational BSC for energy management cooking process

Once the e-KPIs are chosen, it is necessary to outline the variables that affect the e-KPIs. Considering that the top management e-KPIs are an aggregated result, the focus of the outline was the lower hierarchical levels 2 and 3. For complexity reasons, in this fieldwork, the scope was the fiber area and the cooking processes, i.e., one of the four possible. To find the variables, a BSC was created for energy management considering the objectives of the cooking process. The goals were outlined during a two weeks internship in the field with the assessing of the field operators and with the help of the energy mill manager. The objectives statement process was as follows: the operational and quality objectives were outlined along with its KPIs, then the varia which affected those objectives were identified. From the variable defined, those who influenced the consumption of energy were highlighted as energy-related indicators, and, for them, objectives were stated.

	Level 1	Fiber Area, Cooking Department (Level 2,3)	
Perspective	**Objectives**	**Objective for the section**	**Indicator**
Financial	Increase the profitability of the inflows	Guarantee necessary steam characteristics for cooking	T(steam)
	Increase the profitability of the inflows	Improve the reutilization of digestor condensates	Conductivity
	Increase the profitability of the inflows	Improve the reutilization of black liquor	B.liq/W.liq
	Improve the energy efficiency of the equipment	Cyclone heat exchanger performance - basic analysis	1 - TL/TH
	Improve the energy efficiency of the equipment	Cyclone heat exchanger performance - basic analysis	1 - TL/TH
	Improve the energy efficiency of the equipment	Cooking heat exchanger performance - basic analysis	1 - TL/TH
	Improve the energy efficiency of the equipment	Cooking heat exchanger performance - basic analysis	1 - TL/TH
Internal Business Processs	Increase the monitoriation and control of energy in the process	Assure that the cooking process does not stop due to lack of raw material	C 022
	Increase the monitoriation and control of energy in the process	Assure that the cooking process does not stop due to lack of woodchips	M5
	Increase the monitoriation and control of energy in the process	Assure that the cooking process does not stop due to lack of white liq.	T101
	Standardize the minimum energy consumption	Stabilize the pressures in the line	Ph
	Standardize the minimum energy consumption	Stabilize the Extraction flow at the low cooking	m3(black liquor)
	Standardize the minimum energy consumption	Guarantee the rotational speed of the bottom scrapper close to design conditions	Nscrapper
	Reduce process energy waste	Stabilize the extracting pressures	P1 & P1
Learn & Growth	Enhancement employee energy management knowledge	Take maximum advantage of the energy management tools	Time spend in e-tools
	Enhancement employee energy management knowledge	Take maximum advantage of the energy management tools	depth of search
Costumer	Excelent Pulp	Guarantee the quality of the pulp	Kappa
	Excelent Pulp	Guarantee the cooking temperature the top	Temp (Top)
	Excelent Pulp	Guarantee the cooking temperature the bottom	Temp (Top)
	Excelent Pulp	Assure the alkaline quality of the pulp	%alkaline charge
	Excelent Pulp	Guarantee the cleanliness of the pulp	m3water
	Excelent Pulp	Guarantee the amount of liquor for cooking	White liq./mad
	Excelent Pulp	Guarantee the intake of white liquor	m3(white liq.)

Figure 25 - Balanced Scoredcard for energy management for Fiber area (Levels 2,3)

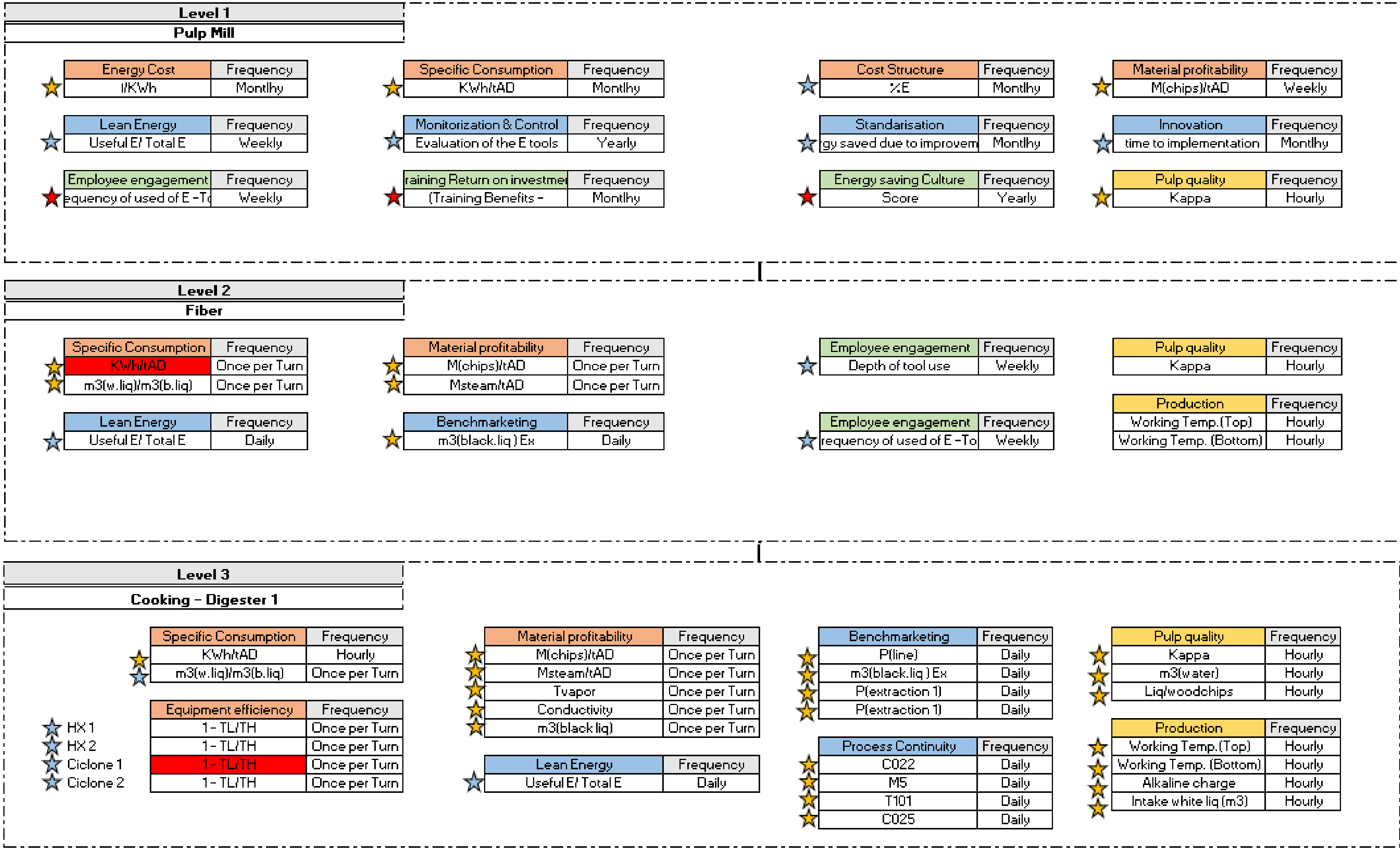

Figure 26 - e-KPI network for the pulping process, fiber area, cooking department

4.4.8 Completed e-KPI network for the pulping process, fiber area, cooking department

With the e-KPIs outlined as well as the variables, the e-KPI network can be created. Figure 26 exhibit the resulting e-KPI according to the different hierarchical levels.

It is important to remark that the proposed e-KPI network is just a suggestion. Different goals will lead to different variables, which eventually will lead to an entirely different e-KPI network. Also, it is essential to mention that the e-KPIs were chosen considering, as much as possible, the opinion of the people that will decide on its assessment; therefore, the e-KPI network can change with time, which means that the resulting network is not static, it is dynamic. Therefore, it is crucial to revise it regularly to ensure that the network is answering the organisation's needs. A thumb rule given by B. Mars [18] is to revise it annually.

Proposed Network vs Actual Network

Since the Navigator company already has an e-KPI network that it is being use for a long time and has proven to be useful for managing and assessing the energy strategy of the company, the proposed e-KPI network was compared to the actual one in order to ensure that it keep the advantages of previous one and bridge its downsides.

	Actual Network	Proposed Network
Hierarchical Levels	3	3
Total nº of KPIs	6	37
Type of information	Aggregated	Aggregated and Disaggregated
Decision making capability assessment	Tactical	Strategic, tactical and operational
KPI assesment areas	Energy	Operational, Quality, Green and Energy
Frequency of measurement	Per hierarchical level	per e-KPI

Figure 27 - Actual Network vs Proposed Network

The comparison took into account the networks structures as well as three significant factors that affect the implementation and the usage of KPIs outlined by the literature. The resulting information is presented and summarised in. As it is possible to see the skeleton of both networks is the same, i.e., the hierarchical level division are identical; the only exception is that in the current network the fiber department is subdivided into four categories instead of three. The reason for this division is due to the consideration that the washer equipment is a significant energy consumer. However, since one operator is responsible for both departments and the equipment do not work independently, the proposed network grouped the washing process under the cooking process, so that the operator could have a all the information he needs clustered.

Regarding the type of information provided by each network, the current KPI network only measures the consumption per department and process, i.e., it gives the result of the consumption but does not tell why the consumption happened. In the company, the consumption information given by the network is used to assess if the energy mission is being achieved or not. Therefore, the proposed network included the e-KPIs that served that purpose and unfold them into a control number of variables affect them using the effect diagram, so that the decision-making process can take into account why and how the energy is consumed.

It is important to remark that the proposed network includes metrics that help to assess the value that the human resources and innovation have in the energy management strategy. This trend could be of great use for the company because its current strategy passes by invest in better equipment and more training for the operators.

Another factor that affects the usage of the network is the frequency of measurement of the KPIs. The actual network attributes the measurement of the KPIs is by hierarchical level, namely: weekly, \daily, or once per turn. This approach was found useful because all the e-KPIs are from the same type and the measurement date corresponds to the end of a working cycle influence, i.e., it is divided such as if an anomaly happens, it can be corrected in the next working cycle. Nevertheless, since the proposed network suggests the usage of a broad type range of e-KPIs, the frequency of measurement is tailored accordingly to the type of decision that can be made by assessing that e-KPI, i.e., inside a hierarchical level can be an e-KPI measured monthly and another measured weekly. For example, inside level one the e-KPI specific energy consumption is measured weekly as in the actual network, but the training return to investment is measured monthly in order to assess if the semesterly workshops are being profitable.

When the actual network was presented, one of the weakness pointed out was that it only provides aggregated information. According to R. Parmenter and B. Marrs [18,29], the origin of the situation could dwell in the fact that the network only uses one type of KPI and does not have sufficient e-KPI per each hierarchical level. Therefore, in order to guarantee the segmentation of the information, the proposed network tried to follow the B. Marr suggestion that said that per each hierarchical level more or less 10 KPI should be stated.

The latest comparison made between the network was the type of e-KPI used by each of them. As previously stated, the actual network only uses one type of e-KPI while the proposed network includes KPIs from different taxonomies, such as operational, quality, green and energy KPIs. By including the other departments KPIs in the management and possible implementation of the e-KPIs, it is expected a better alignment between the operational strategy and the energy strategy of the organisation.

5. Conclusion

In the present dissertation, it was developed a methodology to select (e-KPIs) for improving energy management in manufacturing industries. For that purpose, the current state of the art of KPIs was analysed focusing on: what are their usefulness and the guidelines on how to select them. Additionally, the contemporary knowledge of KPIs for energy management, e-KPIs, was presented, namely, their history, what are the criteria for a variable being considered an e-KPI and current methodologies to select them.

From the state of the art is possible to conclude that independently of the type of KPI, it is indispensable a well-established strategy, an achievable mission and well-defined objectives. Additionally, from the literature review conducted by May G [5], it was possible to infer that there are many tools and guidelines to aid in the selection process of KPIs. However, when it comes to e-KPIs, the methods and tools are not mature. In some areas, the e-KPIs does not provide adequate information to aid in the decision-making process, and, contrary to the business KPIs, the current frameworks do not provide enough help when selecting and stating e-KPIs.

With the gaps identified in the literature review regarding e-KPIs, the initial objectives were strengthened, and a methodology was developed, taking into account the various inputs of the authors referenced.

The present methodology proposes adaptations to some of the well-established frameworks for the statement and selection of KPIs, namely, the BSC and the SMs. The BSC framework intends to align the business objectives and the energy management objectives through the statement of both under the same framework, and with the objectives recognised, attach them metrics to monitor its accomplishment, e-KPIs. The SM framework helps in the correlation process of the goals an metrics. The methodology ends with the statement of the e-KPIs under the ISO22400 framework, and their communication to the company according to the hierarchical level of information they assess.

To test the methodology, it was applied in a real corporate environment at The Navigator Company. To gather the information needed for the methodology implementation, a two-months internship was made to understand the company culture, understand how the products were made and known the key elements in the decision-making process. The outcome of the methodology was a theoretical functional e-KPI network to deploy and manage the organisational energy strategy.

Therefore, it can be said that the present methodology can be an alternative for an organisation state and obtain the key elements, goals and e-KPIs, influences the accomplishment of the sustainability obejectives.

Taking into consideration the above-mentioned, it is expected that the purposed methodology contributes to:

- Express the organisation's sustainability strategy through the use of e-KPIs
- Growth the importance of the e-KPIs in organisations
- Attach the e-KPI to other company's metrics.
- Develop the procedures that help to select e-KPIs

Future work

Even though it was obtained a theoretically capable network to manage the energy of a pulp mill, due to timing and work extension reasons, it was not possible to be tested. Due to the absence of real case information, it is not feasible to conclude the most accurate way for the framework being spread and applied in organisations. For example, it is significant to conclude if the methodology is static or flexible, depending on if the frameworks can be arranged and modified, according to the company's necessities. It will be immensely enriched for the present dissertation and future work to test the network performance in real work environment situations.

Also, the outcome of the methodology was a broad spectrum of KPIs' types; some of them are not usually seen as being related to energy management. It is not possible to conclude if the inclusion of them makes the network richer or lose focus. Therefore, it is necessary to further research to comprehend the pros and cons of incorporating them. Additionally, the present methodology was very focused on energy management, but as previously seen, it can be easily applied for pollutants management. Hence, the present methodology could be one more tool for an organisation to achieve and fulfil the environmental laws; however, due to the lack of real case scenarios, it impossible to conclude the practicability.

Lastly, the present methodology admits that the organisations already know how to state a chose their sustainability mission. However, the identified problem - only two per cent of organisations achieve their sustainability programs - can dwell in the fact of the fact that organisations are not prepared to state sustainability missions and goals.

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7. Attachments

Attachment 1 – Documentation of each e-KPI from the BSC adapted framework.

KPI Description	
Content	
Name	New Energy Production Income
ID	1003
Description	Provide insights into a company's operating efficiency and pricing strategy.
Scope	Pulp Mill
Formula	By dividing the possible new energy production income by the current energy production.
Unit of Measure	%
Range	Min: 0 Max: None
Trend	The higher; the better
Context	
Timing	New Energy Production Income is usually calculated monthly or quarterly as part of the normal management reporting cycle.
Responsible person	Energy Pulp Manager
Production methodology	Continuous
Effect model diagram	

KPI Description	
Content	
Name	Energy price per KWh
ID	1001
Description	Energy price per Kwh is the ratio of the rate at which the company is buying a Kwh.
Scope	Pulp Mill
Formula	E = P/A P – cost of energy A – Amount of energy bought
Unit of Measure	€/KWh
Range	Min: 0 €/KWh Max: None
Trend	The lower; the better
Context	
Timing	Weekly
Responsible person	Energy Pulp Manager
Production methodology	Continuous
Effect model diagram	
Notes	Energy price is a crucial factor in the financial strategy of the company.

KPI Description	
Content	
Name	Process waste level
ID	1005
Description	Getting data on the level of waste in the internal processes will enable companies to identify any problems and put improvements in place.
Scope	Pulp Mill
Formula	Depending on the Lean Process that the company is aiming to improve
Unit of Measure	Tie to the process
Range	Min: 0 Max: None
Trend	The lower; the better
Context	
Timing	Measuring process waste levels follows the companies Lean initiative in which specific key processes are identified and analyses.
Responsible person	Energy Pulp Manager
Production methodology	Continuous
Effect model diagram	

KPI Description	
Content	
Name	Pulp Production Efficiency
ID	1004
Description	Knowing if the main resource is being use efficiently is very important to assess the performance of the process
Scope	Pulp Mill
Formula	P = m/M m – Mass of chip wood entering the process AM– Amount of pulp produced
Unit of Measure	Ton/Tad
Range	Min: The one that guarantee the desired quality of the pulp Max: None
Trend	The closest to the theoretical value for a given quality; the better
Context	
Timing	Weekly
Responsible person	Energy Pulp Manager
Production methodology	Continuous
Effect model diagram	
Notes	Energy price is a crucial factor in the financial strategy of the company.

KPI Description	
Content	
Name	Lean Energy Indicator
ID	1006
Description	The Lean Energy Indicator shows how efficient the equipment is in terms of energy consumption. It represents the ratio of energy consumed for producing saleable products to overall energy consumption of the machine.
Scope	LEI = VEC/OEC
Formula	Derived by dividing the value-added energy to the energy consumption detected in the theoretical production time
Unit of Measure	&
Range	Min: 0 Max: 1
Trend	Closer to 1
Context	
Timing	Measuring process lean energy levels follows the companies Lean initiatives in which specific key machines are identified and analyses, i.e, depends on the current Lean strategy of the company.
Responsible person	Energy Pulp Manager
Production methodology	Continuous
Effect model diagram	

KPI Description	
Content	
Name	Control and Monetarization Audit
ID	1007
Description	An Audit assess if the sensors and monitor capability of the
Scope	Pulp Mill
Formula	Score
Unit of Measure	Dimensionless
Range	Min: 0 Max: 10
Trend	The higher; the better
Context	
Timing	Usually, these types of KPI are measured semesterly or annually depending on the company strategy and financial capability.
Responsible person	Energy Pulp Manager
Production methodology	Continuous
Effect model diagram	

KPI Description	
Content	
Name	Innovation pipeline strength (IPS)
ID	1008
Description	The innovation pipeline strength is less of a defined measure because assessment of the future potential will depend on the product or industry
Scope	Pulp Mill
Formula	IPS = Sum (Innovation project × Future revenue potential)
Unit of Measure	€
Range	Min: 0 Max: None
Trend	The higher; the better
Context	
Timing	IPS is usually measured on a quarterly basis but the frequency can be increased or decreased if the innovation cycles are longer or shorter.
Responsible person	Energy Pulp Manager
Production methodology	Continuous
Effect model diagram	

KPI Description	
Content	
Name	Employee Energy tools engagement level
ID	1009
Description	Employee Energy tools engagement level refers to the engagement of customers with the energy tools provided by the company
Scope	Energy system inside Pulp mill
Formula	Frequency of visit per shift
Unit of Measure	Visits/shift
Range	Min: 0 Max: None
Trend	The higher; the better
Context	
Timing	Reported to the senior team on a quarterly basis.
Responsible person	Energy Pulp Manager
Production methodology	Continuous
Effect model diagram	

KPI Description	
Content	
Name	Training Return On Investment
ID	1010
Description	Shows the business impact of an HR training
Scope	Pulp Mill
Formula	E = BenefitsOfTheHRTraining/CostOfTheHRTraining
Unit of Measure	%
Range	Min: 0 Max: None
Trend	The higher; the better
Context	
Timing	Applied to major training programs.
Responsible person	Energy Pulp Manager
Production methodology	Continuous
Effect model diagram	

KPI Description	
Content	
Name	Energy Strategy Survey
ID	1011
Description	Energy Strategy Survey is a survey answer by the employees of the company to assess if they are aware of the energy policies.
Scope	Pulp Mill
Formula	Score
Unit of Measure	Score (normally from 0 to 10)
Range	Min: 0 Max: 10
Trend	The higher; the better
Context	
Timing	Semesterly
Responsible person	Energy Pulp Manager
Production methodology	Continuous
Effect model diagram	