Deliverable D3.3

Key Performance Indicators for Environmental, Economic and Social Assessment

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Executive Summary

Deliverable 3.3 presents the Key performance indicators for environmental, economic and social assessment to be used as part of DENiM pilot evaluation.

Keyword list

Life cycle assessment, Life cycle cost assessment, key performance indicators, KPI framework, environmental indicators, cost indicators

Disclaimer

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Glossary

CAPEX	Capital expenditures
CED	Cumulative energy Demand
CExD	Cumulative Exergy Demand
CF	Carbon Footprint
DoA	Description of activities
E2BM	Energy Efficiency Benchmarking Methodology
EPD	Environmental product declaration
GHG protocol	Green House Gas protocol
GRI	Global reporting initiative
KPI	Key Performance Indicator
LCA	Life cycle assessment
LCC	Life cycle costing, life cycle cost
LCCA	Life cycle cost assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
LCSA	Life Cycle Sustainability Assessment
MEFA	Material and Energy Flow Analysis
MIPS	Material Input Per Service
O-LCA	Organisational Life cycle Assessment
OEF	Organisation Environmental Footprint
OPEX	Operating expenditures
PCR	Product category rules
PEF	Product Environmental Footprint
S-LCA	Social Life Cycle Assessment
SBTs	Science-Based Targets
WF	Water Footprint

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1 Executive summary

This deliverable reports the activities carried out in the DENIM project, within Task 3.3. The aim of the Task was to identify the assessment domain and granularity required to address the LCA and LCC characterization of the industrial domain object of analysis within the project, by taking into consideration both data available from the DENiM Digitisation Framework and requirements derived by contextual domains. On this basis sustainability KPIs used to assess sustainability (environmental and economic) at factory level, are the main output of this work; the measurement of environmental impacts will be based on the LCA methodology while the economic one on the LCCA one. Even though social indicators have been reported in section 3.3.1, they will not be used as they resulted not strictly connected with the DENiM framework.

Either for LCA and LCCA, the methodology takes into consideration the streamlining of data acquisition and when necessary, the use of existing data, in order to make the methodology rapidly deployable in a real industrial domain. Moreover, considering each of the target pilot sites, the task analysed and defined, wherever possible, the decision-making needs and framing conditions for the assessment of the life-cycle cost and energy saving potential of the improved production processes (e.g., objectives for LCCA, viewpoints, assumptions and boundaries of LCCA, different options that would meet the objectives).

The document is therefore organised as follows. In section 2 the context of the project and the environment where the KPI framework will be applied is briefly introduced. The methodology adopted in order to design the KPI framework is then described.

As a following step, Section 3 describes the in-depth analysis of the state of the art carried out, in order to assess current frameworks, methods and indicators, adopted to communicate and assess resource efficient manufacturing from an environmental and economic perspective.

In order to fully integrate the DENiM context within framework design, Section 4 briefly analyses the technologies supporting DENiM platform and the Pilots cases the platform will be integrated to. The Pilots are either exploited as input providers for framework design, as well as for a first understanding of to which extent the KP framework will be applied to the industrial scenarios pertaining to the project.

Section 5 is eventually the core section of the deliverable that describes the list of indicators, both for the environmental and for the economic perspective, that will be integrated in the DENiM assessment domain, as metrics supporting the optimisation of energy consumption and sustainability impacts of production.

Section 6 eventually draws the conclusions of the work highlighting the main results obtained and the open points that will be addressed in the following Tasks.

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2 Introduction and methodology

This chapter is meant to introduce the work reported in this deliverable, framing it in the DENiM context and briefly discussing the methodology adopted to carry on the activities.

2.1 The DENiM context

The industry sector was responsible for 37% of the total global energy use in 2017, representing a 1% annual increase in energy consumption from 2010, with growth of 1.7% in 2017 following much slower growth of 0.1% the previous year (*IEA – International Energy Agency - IEA*, n.d.). The increase in energy consumption is driven by escalating production in energy intensive industry subsectors.

The primary characteristic of Industry 4.0 is the digitisation of manufacturing processes, which offers opportunities for energy saving through the optimisation of or replacement of technologies, the application of new software tools for energy efficiency management or adaptation in the business processes. Energy efficiency remains one of the most effective short to medium term targets to reduce industry carbon footprint and needs to be considered at all stages of the manufacturing process.

In order to achieve significant energy savings DENiM is meant to provide the ability to collect, analyse and communicate real-time and historical data, to optimise the performance and resource consumption at machine, process and factory, where decision support systems consider energy consumption globally.

The DENiM energy-modelling approach exploits continuous data collection for automated model learning, reduction and selection. In turn, the DENiM adaptive real time energy control strategies for production systems applied at machine, process and factory levels support the simultaneous optimisation of energy use while reducing cost, with the integration of renewables within production system.

Recent innovations in digital technologies (big data, IoT, cloud, machine learning), manufacturing processes (automated control, advanced materials), renewable and distributed power generation all provide opportunities for the creation of sustainable factories and value chains.

More specifically, the convergence of digital technologies and energy management in the manufacturing sector must considered the human factor and the digital skills required to enable workers to make informed decisions with clarity. DENiM develops worker competences in tandem with technological progress. DENiM identifies skills gaps and deploy education and training approaches for developing skills and building competences to support energy awareness and sustainability as part of smart manufacturing processes through the seamless integration of digital technologies, education and training activities. In view of considering the human factor, DENiM considers existing and future regulations from a data protection, legal, ethical and energy policy perspectives and will be used to inform the DENiM technological developments and pilot site intervention.

The synchronisation between the real system and the energy modelling and control strategies is enabled by the DENiM digitalisation framework, which in turn supports the integration of the environmental impact in the Life Cycle Assessment (LCA) and Life-Cycle Cost Analysis (LCCA) tools. The ability to reliably calculate and quantify appropriate metrics and parameters, which provide a clear understanding of the environmental and economic impact (energy use, resource cycles, emissions, resource-use, waste, life cycle cost and cost savings), is a key requirement for sustainable manufacturing. The analysis and reporting of the obtained results in terms of energy savings, environmental, social and economic impacts, have become indeed instrumental to comply with national/international regulations, to protect local markets from unfair competition, to allow

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manufacturers to differentiate their products, to improve consumer awareness on the sustainability topic, and to enable production reconfiguration and optimisation based on sustainability performances (Dendler, 2014). For these reasons, proper metrics and assessment methodologies (such as LCA and LCCA) must be adopted enabling the standardized calculation of appropriate indicators measuring the economic, environmental and social performances at product and company levels. Monitored data empower performance optimization, support to guarantee standardization and legal compliance, sustainability communication and marketing (Bicalho et al., 2017). The exploitation of indexes is recognized to be an effective support to decision-making (Confalonieri et al., 2016), allowing designers and managers to check the current sustainability performances, fix benchmarks and thus (i) promote product, processes, company and supply chain sustainability enhancement, and (ii) understand where to (re)act in order to obtain more effective improvements. Eventually, being sustainable is becoming a picklock to satisfy or even reach sustainability-conscious customers, thus reports and labels based on reliable measures have grown to inform and differentiate market perception of products and brands (Kralisch, n.d.).

In this context, the activity reported in this document defines robust key performance indicators (KPIs) and provides mechanisms to quantify the environmental and cost-related impacts of manufacturing processes and products along their entire lifecycle. This is crucial so that product designers, production managers' and right through to operators can be supported and advised on how to incorporate energy efficiency as a fundamental input to their decision-making process using DENiM decision support tools.

2.2 Relation with other activities within the project

As a conclusion of this chapter, a short highlight about how Task 3.3 integrates within the DENiM activities is reported in the following picture.

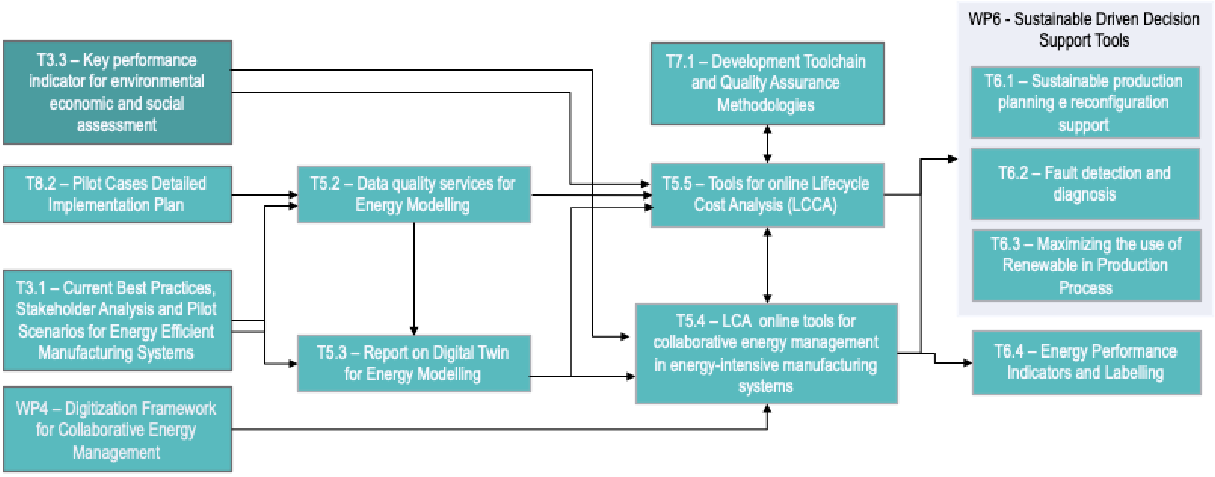

Figure 1: Position of T3.3 within the main activities of DENiM related to it

The designed framework becomes the input for the two tools supporting the calculation of the LCA and LCCA impacts that, in turn will be exploited in WP6, to support the optimisation of company performances under the environmental and cost perspectives. Having the role of posing the base for the following tasks, the model developed in T3.3 will be fine tuned for the different applications in WP5 and 6.

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2.3 Methodology behind the work

The objective of the work is to design the framework that will support the different levels of the DENiM platform in the acquisition, elaboration and presentation of the information and data required to optimise the performances of the company under the sustainability perspectives. To this end the activity, whose main focus is the design of the assessment methodology and the indicators to analyse production life cycle and costs under the sustainability perspective, will take into account the principal elements where the indicators are framed in.

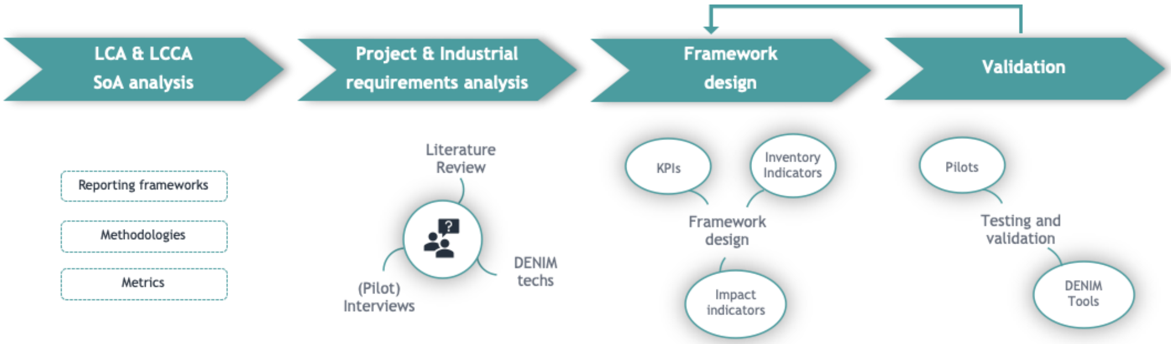

Figure 2: Methodology adopted within T3.3

To this end, as the main objective is to design a KPI framework compliant with the project requirements, industrial expectations and current standards in terms of assessment and reporting in the environmental and economic matter, the activity was based on two main inputs aiming at encompassing the abovementioned requirements. In a first instance a detailed State of the Art was conducted, this giving an extensive overview of reporting frameworks, methodologies and indicators currently adopted to analyse environmental and economic impacts.

In parallel, two iterations of workshops have been conducted, internally to T3.3 and in collaboration with WP8, in order to deep dive the status and requirements deriving from the industrial end-users and exploit their expertise to validate the indicators/methods identified in the previous steps, and understand the level of adoption at industrial level.

All the previous information, together with an assessment of technologies active inside the project, have been integrated in the design of the KPI framework that will support the assessment and optimisation of DENiM industrial facilities.

As a last iteration, a validation of the model is conducted. The activity, started in T3.3 and continued in WP5 is meant to provide indications for a fine tuning of the framework and its finalisation.

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3 Introduction to LCA, LCCA and related KPIs in the DENiM context

As an input to the development of the indicators' framework of DENiM, this section analyses and discusses the main areas related to LCA and LCCA analysis. The chapter is therefore divided into three main sections, the first one considers and describes the main methods and sub-methods, which provide the background for the reporting phase. In the second section, reporting methods in the environmental field contain the guidelines to be applied to have a certification or evaluation of environmental impacts are explored. In the third section of the chapter, the main indicators associated with the assessment and reporting methods described in the first two sections are discussed in depth.

3.1 Methodologies for sustainability assessment

In the last decade, numerous methods for quantifying and evaluating sustainability have been developed (Zijp et al., 2015). The background approach is Life Cycle Thinking (LCT), which means that a system, e.g., a product, a service, or an organization, is considered from cradle to grave, or in a more modern vision, from cradle to cradle. This concept integrates three dimensions into the sustainability assessment: environment, economy, and society. The most crucial methodology in LCT combines with life cycle based are Life Cycle Assessment (LCA), Life Cycle Cost (LCC) and Social Life Cycle Assessment (S-LCA).

In addition to these three methods, the review (Wulf et al., 2019) suggests and adds a possible macro category for the methodologies to assess sustainability, the Life Cycle Sustainability Assessment (LCSA), which also derives from Life Cycle Thinking. All these main assessment methods are based on the ISO 14040 framework (*ISO 14040:2021*, n.d.; *ISO 14044:2021*, n.d.). This framework defines the four main phases to perform an assessment: goal and scope definition, life cycle inventory, life cycle impact assessment and interpretation. Considering the needs and objectives of the DENiM project, it has been decided to consider as a basic methodology for the assessment of the environmental impact the LCA, and as regards the cost aspects, LCC. Therefore, the following chapter deepens the selected methodologies and briefly analysed a series of sub-methods or correlated methods to have a complete vision.

3.1.1 Life Cycle Assessment (LCA)

Life Cycle Assessment (LCA) is the most mature and standardized methodology for the evaluation of the environmental burdens created. It was developed in the 1970s and is a structured, comprehensive, and internationally standardized method defined by the ISO 14040 since 1997. The LCA quantifies all relevant emissions, resources consumed, related environmental and health impacts, and resource depletion issues associated with any good or service ("system"). In other words, LCA considers a product´s full life cycle: from the extraction of resources, through production, use, and recycling, up to the disposal of remaining waste (European Union, 2010). Since 2013, the European Commission has launched the Environmental Footprint methods, to improve the comparability of LCA as applied to products and organizations.

LCA is based on four main phases: 1) goal and scope; 2) inventory analysis; 3) impacts assessment; 4) interpretation.

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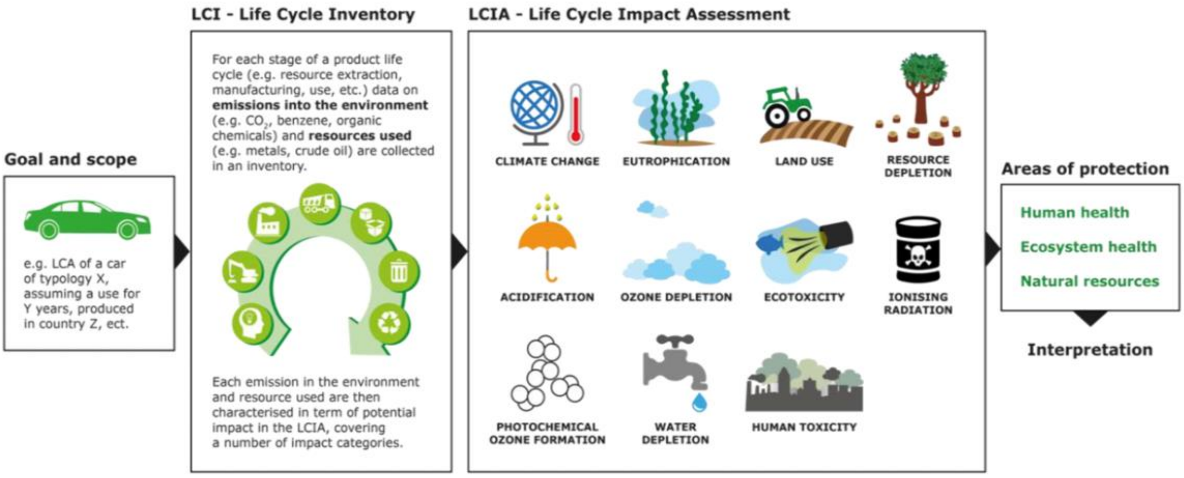

e.g. LCA of a car of typology X, assuming a use for Y years, produced in country Z, ect.

For each stage of a product life cycle (e.g. resource extraction, manufacturing, use, etc.) data on **emissions into the environment** (e.g. CO_2, benzene, organic chemicals) and **resources used** (e.g. metals, crude oil) are collected in an inventory.

Each emission in the environment and resource used are then characterised in term of potential impact in the LCIA, covering a number of impact categories.

Figure 3: Life Cycle Assessment steps: goal and scope definition, life cycle inventory, life cycle impact assessment and interpretation

The goal and scope phase establishes the study's objectives, including the intended application, the reasoning for conducting the study, and the intended audience. This step makes significant methodological choices, including the proper definition of the functional unit, the delineation of the system's boundaries, the delineation of the allocation procedures, the impact categories studied and the Life Cycle Impact Assessment (LCIA) models used, as well as the delineation of data quality requirements.

Life Cycle Inventory (LCI) phase involves the data collection and calculation procedure for the quantification of inputs and outputs of the studied system. Energy, raw materials, and other physical inputs, goods and co-products, waste, emissions to air, water, and soil, and other environmental factors are among the inputs and outputs. When performing LCI, two types of data are involved. The first called foreground data, are specific data necessary to model the system, the second called background data, are more generic information usually related to energy, material and transport, which can be found on databases.

In the Life Cycle Impact Assessment (LCIA) phase, LCI results are associated with environmental impact categories and indicators. This is accomplished using LCIA methodologies, which classify emissions into impact categories before characterizing them into common units for comparability. Finally, results from LCI and LCIA are interpreted in accordance with the declared purpose and scope in the Life Cycle Interpretation phase. Checks for completeness, sensitivity, and consistency are included at this stage. This stage also addresses the uncertainty and correctness of the generated results. (Sala et al., 2016)

3.1.2 Life Cycle Cost Analysis (LCCA) – Life Cycle Costing (LCC)

Life cycle cost analysis (LCCA), and in other word, Life Cycle Costing (LCC), is a process to determine the sum of all expenses associated with a product, process, sub-process, or project, including acquisition and all associated costs, operation, and maintenance (O&M), refurbishment and retirement costs. (“IEC,” 2017; *ISO 15663:2021*, n.d.)

The LCCA process consists of several steps which are described roughly in this chapter. Each step can be more or less analytical in depth, depending on how detailed data is available and how accurate results are required. Procedure might need to be conducted several times before the final decision takes place. For example, in the beginning several options might be analysed by rough and easily found data and after that few options can be selected for the detailed analysis.
The first step of LCCA is to define the scope and the baseline. The “scope” means aspects, such as whose cost, cost savings and benefits count, what is the scope of the activities to be modelled, and

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who are the main stakeholders etc. An essential part of this step is to generate options that would meet the stated objectives and to develop a baseline, or to determine a "business as usual" scenario e.g. without DENiM developments. All the assumptions and boundaries of the analysis (e.g. budget, earlier decisions) need to be defined as well.

Step 1	Structuring the business case and solution to be assessed	Which solution(s) do you want to assess? Who are the decision-makers? In which phase of the decision-making process will the assessment be conducted? Which is the viewpoint of the assessment? Whose benefits and costs count? Which major stakeholders are likely to be affected?

Step 2 focuses on the identification of the cost categories. In order to estimate the life cycle cost, it is necessary to first divide the costs for applicable costs categories. The proposed categorisation can later be used as the default structure and basis when assessing the life cycle cost of DENiM developments and applications in the pilots.

Step 2	Cost breakdown structure	Can costs and cost savings be categorised somehow? Which cost elements of the selected solution(s) are typically relevant, which are not? (i.e. "high cost items")? How about the risks related to digital solutions e.g., DENiM developments and their deployments?

LCCA requires wide variety of data which can be collected from different data sources. Detailed data collection process needs to be defined when data needs are specified in steps 1 and 2. The main issue in data collection is to ensure the quality of data that will be used in calculations. Quality and reliability of assessment results are correlated to quality of data used in the analysis. When compromises are necessary, decision-makers need to be aware which data quality dimensions are decreased. On the other hand, it is good to consider that high quality data is not always the most accurate for example. Decision-making situation inherently includes lot of uncertainties which cannot be removed and thus is not worth putting efforts to collect data with high precision when needed information can be produced even with inexact data. When planning data collection, relevancy dimension should be considered carefully as it can reduce data collection efforts.

Step 3	Data collection • Cost values, non-monetary data • Other calculation parameters	What are the main data sources for costs and cost savings? How could the data on intangible criteria (i.e. non-monetary value elements) be collected? How about the data on risks? Calculation parameters: What is the typical time span/calculation term for the evaluation? What discount rate(s) do you typically use? Why? Etc.

In valuation phase, monetary values should be given to costs and cost savings. Often, for example, engineering and manufacturing estimates for costs and related profits are available (market prices). Older estimates available may be updated to the present time of appropriate factors, such as annual discounting and escalation factors. In addition, it should be taken into account that comparing cash flows from different periods can be achieved only by incorporating the time value of money (discounting). Although discounting is a generally accepted practice, the applied discount rate is often

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controversial. In business circles, high discount rates are applied such that current financial flows have a higher weight. In contrast, from a societal or environmental point of view, low discount rates are preferred to avoid the fact that current activities impose large costs on future generations (Hoogmartens et al., 2014).

By applying consistent and well-documented assumptions, a justified assessment of costs and cost savings can be prepared. Evaluation means determining the value or worth of an option being considered in a specific decision situation. It involves determining and understanding the consequences of the DENiM developments.

Step 4	Framework development and testing Result calculations (numerical and graphical)	What are typical decision/ acceptability criteria and measurement indicators you use and calculate? ○ Financial indicators ○ Risk indicators ○ Other How do you make the ranking of alternative options if needed? How the decision is finally made (e.g. based on calculations, visions…)?

LCCA in DENiM is performed before the costs, cost savings and benefits are realized. Thus, the calculations are based on estimates of future values, which are inherently uncertain. If calculation parameters are highly uncertain, it obviously leads to uncertain results which do not provide enough information for decision making. Point estimates are typically used in decision making, and thus it is important to analyse uncertainty related to the analysis results. Sensitivity analysis can be performed e.g., by Monte Carlo simulation which is useful especially when uncertainty of several calculation parameters needs to be considered at a same time. If uncertainty of only one or a few calculation parameters is considered the simple what-if calculation can be conducted i.e. result values are re-calculated after the selected calculation parameter value is changed.

Step 5	Sensitivity analysis	Which assumptions need to be tested? What comes out if you change parameters? How sensitive are the results to changes in estimates and model features (assumptions)? What are the ranges of values of costs and cost savings, discount rate, lifetime etc. that are appropriate for testing? How would you see the difference in decision criteria and indicators when using only optimistic and then only pessimistic estimates?

After completing the assessment, the results are ready to be put to practice. Results and recommendations can be reported in written form.

3.1.3 Other sustainability assessment methods and tools

Carbon Footprint (CF)

The concept and name of the carbon footprint derive from the ecological footprint concept, which was developed by (William E.Ree & Mathis Wackernagel, 1996) in the 1900s. While carbon footprints are usually reported in tons of emissions (CO_2-equivalent) per year, ecological footprints are usually reported in comparison to what the planet can renew. Carbon footprints are part of a family of footprint indicators that also includes ecological, water, and land footprints. Carbon footprint (CF) represents net emissions of CO_2 and other greenhouse gases over the full life cycle of a product,

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process, service or organisation. Normally, it is expressed as a CO_2 equivalent (usually in kilograms or tonnes per functional unit) and as such is equivalent to the usual LCA impact category Global Warming Potential (GWP). CF provides a standard approach (*ISO 14064-1:2019*, n.d.) to calculate the net emissions of CO_2 and other greenhouse gases over the full life cycle of a product, process, service or organization. The CF can be calculated using the LCA standard (ISO 14044) as well as other standards largely in compliance with it, such as the GHG Protocol.

Water Footprint (WF)

The water footprint (WF) is one of the environmental footprints which measures the amount of water used to produce each of the goods and services. It can be measured for a single process, for a product and for entire multi-national company. According to the standard ISO14046 definition, the WF include the metrics that quantify the potential environmental impacts related to water, and a water footprint assessment is thus the compilation and evaluation of the inputs, outputs and the potential environmental impacts related to water of a product, process or organisation. The WF is based on the LCA methodology and the link between these methods of analysis is very strong, so much so that a Water Footprint study can stand alone or be integrated within a more comprehensive LCA. (*ISO - ISO 14046:2014 - Environmental Management — Water Footprint — Principles, Requirements and Guidelines*, n.d.; *UNI EN ISO 14064-1:2019*, n.d.; *Water Footprint*, n.d.)

Cumulative energy Demand (CED) and Cumulative Exergy Demand (CExD)

Cumulative Energy Demand (CED) represents the energy demand, valued as primary energy during the complete life cycle of a product. This methodology can be considered as a sub-method of the broader LCA method. The application of CED to a single product, represents the direct and indirect energy use throughout the life cycle, including direct and indirect uses of energy. Compared to complete LCA studies, the calculation of CEDs requires less information in the inventory analysis. (Huijbregts et al., 2006) Despite its popularity, there is no harmonised approach yet and the standards and guidelines define the cumulative energy demand differently. In the research done by (Frischknecht et al., 2015) an overview of existing and applied life cycle based energy indicators, classified the different approach to cumulative energy demand calculation in two main concepts, which differ by the conversion efficiency of the energy collecting facility. The analysis demonstrates that the "standard CED" energy harvesting approach quantifies the energy content of all available energy sources (renewable and non-renewable). The "standard CED" approach and the resulting impact category indicators reflect the theme of "energy resource conservation" but not (any other) environmental impacts.

The Cumulative Exergy Demand (CExD) was proposed by (Szargut et al., 1987)It is defined as the sum of exergy of all supplies required to produce a product or provide a service (Bösch et al., 2007). CExD is related to Cumulative Energy Demand (CED), but unlike CED, it can account for materials and quality of energy inputs. In addition to this advantage, CExD analysis can provide insight into potential improvements and for comparing alternative products, by accounting for exergy use throughout the life cycle (Nwodo & Anumba, 2020).

Eco-Efficiency Analysis

The eco-efficiency analysis and portfolio provides as a decision-making aid for a variety of strategic and marketing issues. Eco-efficiency is one of the key goals in corporate environmental management. Since its first academic development by (Schaltegger S & Sturm A, 1990) and its prominent promotion by (Stephan Schmidheiny, n.d.) and the World Business Council for Sustainable Development (Verfaillie, n.d.), eco-efficiency has been operationalized on various levels and for many different kinds of applications.

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The approach has been refined over the last decade and applied to a variety of projects since its academic inception. An eco-efficiency analysis of products allows assessing different options to fulfil a customers benefit and includes the consideration of the whole life cycle of the products. The EEA Is closely connected to LCA for the environmental part of the ratio and LCC for the economic and ecological part (Kicherer et al., 2007). The majority of EE methods produce one or more indicators, which express the relationship between an environmental and an economic/financial variable. Companies, products, and countries can all be compared using EE and its indicator(s). The framework can be used for benchmarking and monitoring, as well as cross-temporal comparisons. Different weighting and normalization approaches can be used, but they are not yet harmonised.

Eco-efficiency analysis method form BASF

BASF established this holistic method in 1996 and was one of the first companies in the chemical industry to do so. The Eco-Efficiency Analysis follows ISO 14040:2006 and 14044:2006 for environmental LCA. This method take into account the environmental impact in proportion to product's cost-effectiveness, thus consider economic and environmental equally. The environmental impacts are determined by the method of LCA, and economic data are calculated with conventional method.(Saling et al., 2002)

SEEBALANC: Socio-Eco-Efficiency Analysis

SEEBALANCE is an innovative sustainability assessment method developed by BASF that allows the assessment not only of environmental impact and costs but also of the societal impacts of products and processes. The aim is to quantify performance of all three pillars of sustainability with one integrated tool in order to direct and measure sustainable development in companies. SEEBALANCE has been the result of a cooperation (2002-2005) between BASF SE and various academic research institutions including the Institute for Geography and Geoecology of Karlsruhe University, Ökoinstitut e.V. and Jena University. The framework was partially developed in a project funded by the German Federal.(Schmidt et al., 2004)

EcoPROSYS: An eco-efficiency framework

The Eco-Efficiency Integrated Methodology for Production Systems (ecoPROSYS), is a decision support tool proposed by Baptista, relies on the use of a systematized and organized set of indicators easy to understand/analyse promoting continuous improvement and a more efficient use of resources and energy. The goal is to assess eco-efficiency performance in order to support decision and enable the maximization of product/processes value creation and minimization of environmental burdens. The framework can be applied to any industry or production system, where all the unit processes involved are identified and the inputs/outputs of each unit system quantified and easily perceived. The results can be used to evaluate the production system's performance and can help to understand which unit processes or aspects play a key role in terms of economic value and/or environmental impact. (BAPTISTA et al., 2014; Baptista et al., 2016)

Commonly used economic evaluation methods

Economic evaluation methods can be classified into different categories like financial assessment, alignment with the strategy, scoring models and checklists (see e.g.(Cooper et al., 2001)). It is worth noting that no method covers all aspects and a variety of approaches should be used.

Financial assessment is usually conducted by means of quantitative measures such as net present value (NPV), internal rate of return (IRR), payback period analysis or profitability index (e.g. (Dayananda et al., 2002; Götze et al., 2015; Keeney & Raiffa, 1993; Pike & Neale, 2003). The main aim of assessments is to provide a basis and a support for better decision making. Efficiently maximizing

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the added value and reducing risks require a thorough understanding of the costs of novel solutions, e.g. digital solutions. This is especially true when given financial resources are limited. In this respect, estimates of and other information on the life cycle costs are crucial for decision making and for the development of strategies and applications for increasing energy efficiency. In the context of DENiM, economic evaluations can be divided into:

- investment appraisal (e.g. life cycle costing, LCC cost-benefit assessment CBA,) of different decision options (ex ante)
- cost assessments (ex post)

Although the primary purpose of economic assessments can be defined as the assessment of the long-term implications of decisions, in real life decisions often are under pressure to demonstrate short-term effects. In addition, assessments emphasize typically too often the evaluation of direct costs, rather than indirect or intangible costs. This is because direct costs are more easily to be monitored. However, especially investments in sub-systems for machinery, like digital solutions, can and do have indirect impacts on profitability and sustainability. For example, the loss of opportunity through disruption of business is typically difficult to assess. (Komonen et al., 2012a; Ojanen, V et al., 2012). Furthermore, production assets in the energy intensive-industry have long life cycles and during the operating time numerous rebuilds, replacements and expansion investments take place which effects are both direct and indirect and which have a strong effect on profitability and sustainability.(Komonen et al., 2012b; Ojanen et al., 2012). Furthermore, production assets in the energy intensive-industry have long life cycles and during the operating time numerous rebuilds, replacements and expansion investments take place which effects are both direct and indirect and which have a strong effect on profitability and sustainability.

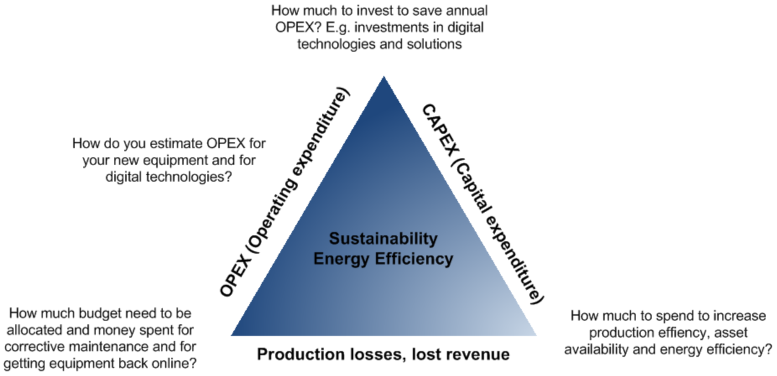

Figure 4: The life cycle costing challenge (adapted from ISO 15663)

The main aim of cost and investment assessments is to provide the basis and a support for better decision making and for improved risk management. Efficiently reducing risks requires a thorough understanding of the costs of novel digital deployments. This is especially true when given financial resources are limited. In this respect, estimates of and other information on the costs are crucial for decision making and for the development of strategies and measures to the life cycle cost.

PROSA: Product Sustainability Assessment

PROSA is a method developed by the Öko-Institut for a strategic analysis and assessment of product portfolios, products and services. The method is typically used for a strategic analysis and evaluation of product portfolios, products and services. The goal of PROSA is to identify system innovations and options for action towards sustainable development. PROSA structures the decision-making processes that this requires, reducing complexity to key elements. Thanks to its open structure, PROSA can also

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be used to analyse sustainability at other levels, such as technologies, large infrastructural projects or geographical units (Grießhammer et al., n.d.).

Energy Efficiency Benchmarking Methodology (E2BM)

Energy efficiency benchmarking is a technique for identifying best practices that serve as possible benchmarks for measuring and managing energy efficiency improvement. Presented by (Y. S. Tan et al., 2015), this methodology, can be applied to both high-mix and low-volume mass production environments. The methodology allows the quantification of energy efficiency gaps between manufacturing operations and corresponding best practices, and thus reveals the potential for achievable energy savings.

Material and Energy Flow Analysis (MEFA)

MEFA is a systematic assessment of the elementary flows of materials and energy within each unitary process of a production system. Such assessment can help evaluate and identify the weak points within the production system. Consequently, the results (efficiency performance) can be used to support decision making with respect to the enhancement of the production system’s overall performance in terms of environmental and economic performance. Assessing the production system’s efficiency via material and energy analysis requires a large amount of data as well as specific knowledge of the process (BAPTISTA et al., 2014).

MIPS: Material Input Per Service

The MIPS method was developed in the early 1990s by the Wuppertal Institute and is a global framework which provide an environmental performance measurement, monitoring and reporting. The MIPS approach provide the measurement for material and energy intensity from processes, products, infrastructure and service in our economic system (Fani Cahyandito, n.d.). MIPS calculates resource use from the point of extraction from nature: all data corresponds to the amount of moved tons in nature, corresponding to the categories of biotic or renewable raw material, abiotic or non-renewable raw material, water, air, and earth movement in agriculture and forestry. All material consumption is calculated back to resource consumption during manufacturing, use, recycling, and disposal. Simple calculation factors for energy consumption or transportation, expressed in t/MWh or t/tkm, are used to accomplish this. In addition, the key distinction from indicators that measure outputs (emissions) is the active pursuit of sustainable products and services, rather than just the reduction of emissions caused by existing products and product families. The MIPS can be considered as a sub-method of the broader LCA method (Rohn & Liedtke, 2002).

3.2 Reporting methods

Since the 1990s, the global community has been developing a series of guidelines and standards to support organisations in assessing their emissions and environmental impact in order to meet the targets set by European ((*2030 Climate & Energy Framework | Climate Action*, n.d.) and international institutions (Kyoto pact).

The optimisation of energy consumption is a crucial activity to reduce environmental impacts and to implement a suitable reduction with a view to improving production processes; it is essential to use tools and standards that allow an organisation to report and analyse the current situation. Furthermore, it could be helpful to calculate the carbon footprint, a measure of the total amount of greenhouse gases emissions, expressed in CO_2 equivalent, caused directly or indirectly by the organisation or its products. There are different standards and guidelines for reporting greenhouse gas emissions and determining the carbon footprint, depending on whether it is talking about products and services or organisations.

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A further step can be a Corporate Social Responsibility (CSR) standard, increased in number and popularity in the last years. Literature review and research identified more than 300 global corporate standards, each with its history and criteria. In this scenario, we select some of the most relevant standards concerning DENiM aims.
The following are some standards developed over the last 30 years, which are useful in the context of corporate and product energy efficiency.

GHG protocol – Green House Gas protocol

The Greenhouse Gas Protocol (*Greenhouse Gas Protocol |*, n.d.)) was created in the late 1990s as an international standard for greenhouse gas accounting, which was needed in view of the evolution of international policies on climate change. The standards are designed to provide a framework for businesses, governments, and other entities to measure and report their greenhouse gas emissions in ways that support their missions and goals. The GHG Protocol considers the emissions of the following six climate-altering gases (capable of contributing to global changes in the Earth's climate): carbon dioxide (CO_2), sulphur hexafluoride, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons.
According to the protocol, the emissions of these climate-changing gases are divided into two macro groups: direct emissions, those coming from the organisation's sources, and indirect emissions, those that are the consequence of the organisation's activity but whose source is controlled by other organisations. In a high-level analysis, the protocol is structured in three scopes: In the first scope (compulsory calculation) is asked to calculate all the company's direct emissions, deriving from the use of fuels for energy production, for company vehicles, for the production process, as well as those deriving from the use of chemicals for production processes and other so-called "fugitive" emissions, such as leaks from mechanical systems or methane emissions from organic deposits. The second scope (mandatory calculation) is asked to calculate emissions from purchased electricity or steam, hot or cold carrier fluids. These energy sources produce indirect emissions, as their physical production takes place outside the company and is not under its control. The third scope is optional, and it requires the calculation of indirect emissions related to all the remaining activities carried out by the company in analysis. Scope 3 is the broadest one since it includes upstream activities (e.g. those related to the production and transportation of the purchased material and components), inner activities (e.g. business travels and production waste treatments) and downstream ones (e.g. distribution and use of the products).

ISO 14064

In March 2006, the international organisation for standardisation (ISO) completed its four-year development of (*ISO 14064-1:2019*, n.d.), a three-part international standard for GHG management activities, including developing entity emission inventories. The standards include minimum requirements for GHG inventories, which provide a basic structure for credible and consistent independent auditing. In addition, ISO 14064 offers organisational users' opportunities for improved consistency, increased flexibility and decreased effort associated with voluntary GHG inventories. The Structure of ISO 14064 consists of three parts, each with a different technical focus. Part 1 of the standard is titled "Specification with guidance at the organisation level for quantification and reporting of greenhouse gas emissions and removals." This part of the standard addresses conducting greenhouse gas emission inventories of organisations such as corporations using a bottom-up approach to data collection, consolidation, and emissions quantification. Part 2 of the standard addresses quantification and reporting of emission reductions from project activities. Part 3 of the standard is titled "Specification with guidance for the validation and verification of greenhouse gas assertions." This part of the standard establishes a process for verifying a greenhouse gas statement, including organisation inventories, regardless of whether or not the inventory was developed under

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Part 1. This verification process is also applicable whether the verification is being conducted by an independent third-party verifier or by an organisation's internal auditors.

IEC 60300 Dependability management - Part 3-3: Application guide - Life cycle costing

IEC 60300-3-3: 2017 Life cycle costing establishes an introduction to the concept of life cycle costing (LCC) and it covers all applications. This standard particularly highlights the costs associated with the dependability of an item (e.g. individual part, component, device, functional unit, equipment, subsystem, or system which may consist of hardware, software, people or any combination). The standard is giving guidance on life cycle costing and is aimed at for use by managers, engineers, finance staff, and contractors, to intended to assist those who may be required to specify and commission such activities when undertaken by others. The third edition (2017) is the latest edition and constitutes a technical revision including e.g. addition of a complete analysis process, greater reference to international accounting practices and increased discussion of financial concepts. (“IEC,” 2017)

The LCC can be used and applied throughout the life cycle for making decisions for applications such as: project planning, budgeting and funding, acquisition processes, feasibility studies, concept development, selection of alternative design solutions, assessment of remaining life and comparison between new system acquisition and renovation of a current system (“IEC,” 2017). Thus, it is very applicable also to be used to assess the cost savings generated by the DENiM developments.

ISO 15663 - Petroleum, petrochemical and natural gas industries — Life cycle costing

The new ISO 15663 issued in February 2021 contains requirements and guidance on how to apply life cycle costing methodologies to provide decision support for selection between alternative competing options (e.g., projects, operational and technical subject matters) and strengthen the industry cost management for business value creation. The standard is particularly focused on the cost management within the oil & gas and energy industries, but it is also applicable for other energy industries, and the common procedures are also valid in other industry branches. HSE, sustainability and climate change considerations in the context of life cycle costing are also addressed in ISO 15663. (*ISO 15663:2021*, n.d.)

The standard gives guidance for how to apply and address (ISO, 2021):

- Key economic evaluation measures such as life cycle cost (LCC), Net present value (NPV), payback period and break-even price
- Capital expenditure (CAPEX), operating expenditure (OPEX), and revenue factors (REVENUES or LOSTREV)
- Analysis techniques and models, with required data input
- Identification of cost elements and cost drivers
- Required extent of planning and management of life cycle costing across life cycle phases
- Common and specific contractual considerations for operators, contractors and vendors

GRI – Global Reporting Initiative

The GRI is a principle-based standard focus on changing corporate reporting standards to help firms communicate information on their social, economic and environmental impact in a comparable way. The GRI Standards create a common language for organisations to report their sustainability impacts consistently and credibly. This enhances global comparability and allows organisations to be transparent and accountable. In addition to reporting companies, the Standards are highly relevant to many other groups, including investors, policymakers, capital markets, and civil society. The GRI standards are designed as an easy-to-use modular set, starting with the universal Standards. Topic Standards are then selected, based on the organisation's material topics: economic, environmental or

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social. This process ensures that the sustainability report provides an inclusive picture of material topics, their related impacts, and how they are managed. It should be noted that the GRI guidelines are not a simple summary of a variety of performance indicators. A considerable part of the guidelines is devoted to selected principles defining how the report is supposed to be compiled. The consideration of the process-dimension of corporate responsibility reporting (How do we prepare our report?) is a specific strength of the GRI guidelines since it allows managers to deliberately reflect on the way the report is constructed over time. The GRI structure is divided into two main topics. The universal standard (101, 102, 103) and the specific standards: GRI 200 (economic aspect), GRI 300 (environmental aspect), GRI 400 (social aspect). (*GRI Standards*, n.d.)

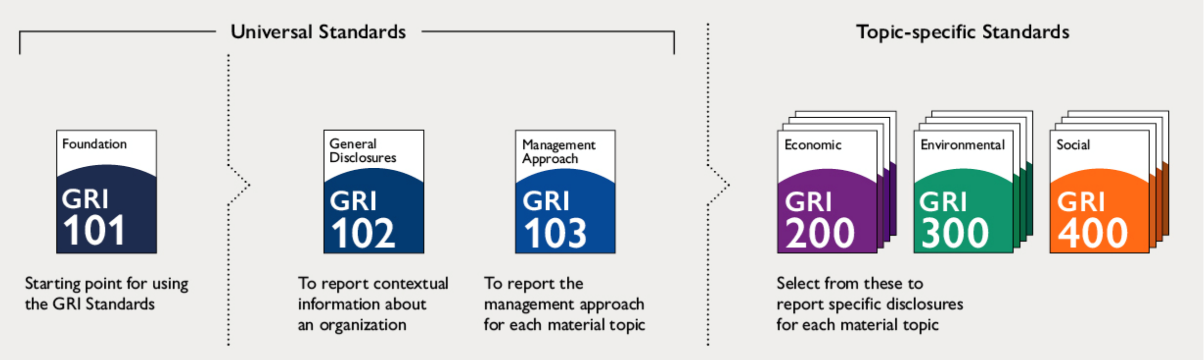

Figure 5: Structure of the GRI Standards

Based on DENiM's requirements, we decided to focus on GRI 300, composed of eight different environmental aspects.

- 301- Materials
- 302 - Energy
- 303 - Water and waste water
- 304 - Biodiversity
- 305 - Emissions
- 306 - Water discharges and waste
- 307 - Environmental compliance
- 308 - Supplier environmental assessment

Science Base Target

Science-Based Targets ((*Ambitious Corporate Climate Action - Science Based Targets*, n.d.)) are GHG emission reduction targets whose ambition is in line with the decarbonisation level required to keep the global temperature increase below 1.5°C, as described in the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), and the Paris Climate Agreement. Science-Based Targets provide a clearly defined pathway for companies to reduce greenhouse gas (GHG) emissions, helping prevent the worst impacts of climate change and future-proof business growth. The Science Based Targets initiative allows businesses to choose from seven target-setting methods. For instance, companies can make contributions based on total GDP, or take a sector-based approach that divides industry responsibility. This flexibility enables companies to set targets that are most relevant to them and account for the sector's dynamics. As part of the criteria for setting a science-based target, the target boundary must be company-wide, covering all emissions included in the Greenhouse Gas Protocol. Moreover, the commitment period must cover a minimum of five years from the target announcement date. Companies are also required to disclose their greenhouse gas emissions annually along with any other data that shows progress against their targets. Because SBTs include a long-term sustainability vision, companies can think beyond short-term solutions to reduce GHG emissions.

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In general, GHG emission reductions' quantifiable benefits include cost savings, energy savings, and an improved bottom line.

O-LCA: Organisational Life cycle Assessment

By the standard ISO/TS 14072, the O-LCA is being described as: "a collection and evaluation of inputs, outputs and potential environmental impacts of the activities associated with the organisation adopting a life cycle perspective and since the portfolio of an organisation usually includes more than one product, all goods and services provided by the organisation are evaluated simultaneously".

O-LCA follows the same four-step methodology as LCA, thus requiring clear definitions, reference units, a defined system boundary, lots of high-resolution data, allocation procedures, identification of hotspots, etc. In addition, the O-LCA approach is considered multi-impact environmental, which means that a full range of environmental issues relevant to the specific system is considered, representing the organisation's activities' potential environmental impact profile. Martinez-Blanco (*Guidance on OrGanizational Life Cycle Assessment*, n.d.) organises the O-LCA goals into three groups: analytical objectives, management objectives and social objectives. O-LCA is envisioned for organisations of all sizes, both public and private, in all sectors and worldwide. Furthermore, the guidance document defines the so-called "experience-based implementation pathways" and provides methodological support according to the organisation's previous experience with other environmental tools. Eleven experiences of the so-called "First Movers" of O-LCA illustrate the process and benefits that the methodology could bring to organisations. Eight sectors and four regions are represented in the case studies.

Organisation Environmental Footprint (OEF)

The Organisational Environmental Footprint (OEF) originates from the European Commission Recommendation 2013/179/EU of 9 April 2013 and is defined as a multi-criteria measure of the environmental performance of organisations providing products/services in a life cycle perspective.

The normative act's general objective is to introduce standardised methodologies at the European level, suitable for identifying environmental impacts related to organisations' activities while taking into account the activities of the supply chain and integrating tools currently used by organisations.

An OEF study is intended to measure the potential environmental pressures related to the organisation's provision of products. The method requires a reference unit for assessment, parallel to the concept of "functional unit" in an LCA study. Still, in this case, the organisation is the reference unit for an OEF analysis. To calculate the OEF, an organisation's function is to provide goods and services over a specified reporting interval. The organisation and its product portfolio define the system boundaries for the analysis. During this European project, it has been developed a Sector-specific guidance for calculating and reporting organisations' life cycle impacts, the Organisation's Environmental Footprint Sector Rules (OEFSR). The OEFSRs help focus OEF studies on those aspects that are most relevant in determining an organisation's environmental performance in a given sector, thereby reducing the time, effort, and money needed to do an OEF study. OEFSR takes a step further by identifying significant impacts common to a sector, comparisons and comparative assertions against a reference system, and the identification of significant environmental impacts common to a product group (Pelletier et al., 2012).

Product Environmental Footprint (PEF)

In parallel to the OEF and OEFSR project, the European Commission has developed and studied a method to measure and communicate products' life cycle environmental performance (PEF). The European Commission also established instructions to defined PEF Category Rules (PEFCR), a ruleset describing how to calculate a specific product group's environmental footprint. The resulting rules have been being applicable in the entire EU market thanks to 26 pilots.

Based on a European Commission Communication in 2013, the Product Environmental Footprint (PEF) and Organisation Environmental Footprint (OEF) guides used during the pilot phase until 2018, can now be applied during the current transition phase until 2021. About 20 Product Environmental Footprint Category Rules (PEFCR) and Organisation Environmental Footprint Sector Rules (OEFSR) documents have been developed in this process, together with industry producers and other private sector and governmental organizations. (Manfredi et al., 2012)

3.3 Sustainability assessment indicators

Nowadays, sustainable manufacturing has become a very important issue amongst industries around the world and it has been recognized as a critical need to achieve competitive advantages. So, one of the main success factors is the implementation of Key Performance Indicators (KPIs) within the triple bottom line of sustainability. Indeed, it has been reported that those companies implementing sustainable practices are able to achieve better product quality, higher market share, and increased profits.

Sustainable manufacturing is defined as the creation of manufactured products that minimize negative environmental impacts, conserve energy and natural resources, are safe for employees, community and consumers and are economically sound. The general principle is to reduce the intensity of material use, energy consumption, emissions, and the creation of unwanted by-products while improving the value of products to organizations and to society (*Sustainable Manufacturing and Eco-Innovation: Towards a Green Economy*, 2009). In order to do so, a research concerning sustainable manufacturing indicators has been carried out with respect to the 3 areas of sustainability, but considering the scope of the project, beyond the standard division among environmental, economic and social indicator, a dedicated section to energy performance indicators is also provided. (*Sustainable Manufacturing and Eco-Innovation: Towards a Green Economy*, 2009). In order to do so, a research concerning sustainable manufacturing indicators has been carried out with respect to the 3 areas of sustainability, but considering the scope of the project, beyond the standard division among environmental, economic and social indicator, a dedicated section to energy performance indicators is also provided.

In order to improve the understanding of the indicators, based on the methodology adopted, a further division among inventory and impact indicators has been made. Once the boundaries of the system have been defined inventory indicators are calculated with the aim of providing useful measures for reporting, monitoring or supporting decision making. However, inventory indicators do not provide any information about the impacts on the environment, so during Life Cycle Impact Assessment (LCIA) inventory data are converted into impacts on the environment through characterisation models.

3.3.1 Inventory indicators

During inventory data collection, data such as raw materials, energy used, waste and emissions generated are gathered with the aim of controlling performances of the system. According to the 3 areas of sustainability, the next sections provide an overview of the currently used indicators in manufacturing industries calculated at inventory level.

Environmental performance indicators

Sustainability is a growing concern for manufacturing companies, as they are major contributors to pollution and consume a relevant portion of the world's natural resources. Thus, it is important to develop quantitative-based strategy to create guidelines for the business processes. In this sense, environmental performance indicators play a significant role in the definition of targets and goals.

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Based on the paper analysed, many indicators were found, and according to (Hristov & Chirico, 2019) these are represented in the Table 1 and described in detail below.

Table 1: Environmental key performance indicators

To reduce gas emissions	To optimize materials usage	To reduce natural resources consumption	To reduce waste and improve the efforts to address "green-ness"
- Emissions of ozone depleting substances - Emissions of GHG - Sulphur dioxides (SO_x emissions) - Nitrogen oxides (NO_x emissions)	- % of waste generated - % of hazardous material - % of reusable/recycled material - % of waste recycled off/on site - Non-renewable material intensity - Weight of restricted substances intensity - Recycled/reused content of material inputs	- Energy intensity - Electricity consumption - Gas consumption rate - Natural cover - Water intensity	- Renewable energy rate - Renewable electric sources rate - Resource efficiency

Regarding gas emissions a set of LCA based indicators is provided. This is useful to quantify the amount of particles in the air, soil and water coming from industrial processes. The first indicator is the *emissions of GHG* that, expressed in kg. of CO_2 eq., measures the amount of greenhouse gases that contribute to climate change (Amrina & Vilsi, 2015; Chengcheng Fan et al., 2010; Rangangouda Patil et al., 2020; Zarte et al., 2019). More analyses introduce indicators such as *emission of ozone-depleting substances* and *emissions causing acid rain* which are measured in kg or m^3 of ozone depleting substances and kg or m^3 of emission of NO_x and SO_x (Chengcheng Fan et al., 2010; Dočekalová & Kocmanová, 2016; Winroth et al., 2012).

To optimize materials usage, different indicators have been developed in the literature. Usually measured in %, kg, m^3 or even kWh over a normalization factor, these allow to better understand what resources are used and how they are managed within a company. (Hristov & Chirico, 2019) introduce the *% of waste generated* to calculate the percentage of waste produced per product unit.

(Chengcheng Fan et al., 2010) discuss the management of toxic waste by introducing the *% of hazardous material over total waste*, this is used to evaluate the percentage of the production of harmful material over the total waste generated by the production process.

More analysis carried out by (H. X. Tan et al., 2015) highlight the importance of reused/recycled material to assess sustainability in terms of material usage. So, they introduce an indicator to evaluate the amount of reusable/recycled material within a production system. Similarly, to have a complete overview of material consumption, (Hristov & Chirico, 2019) introduced the *% of waste recycled off/on site* to investigate how much of the waste produced is reused internally or externally the production site. In addition, many studies have been carried out to identify indicators to improve the efforts to address "green-ness". In this sense, (Winroth et al., 2012) introduced the *renewable energy rate* indicator, which is defined as the percentage of renewable energy used over the total amount. Another important indicator used to monitor electricity consumption is the *renewable electric sources rate*, which is defined as the ratio of renewable electric energy used over the total.

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In terms of resource usage, (Park & Kremer, 2017) identify the *resource efficiency* indicator to assess resource consumption. The concept of *resource efficiency* consists in minimizing the resources used in producing a unit of output and it is expressed as the number (or volume, or mass) ratio of useful material output and material input.

Finally, one of the most important aspects companies are dealing with is how to effectively reduce natural resources consumption. To do so, the Organization for Economic Co-operation and Development (OECD) identify a list of KPIs to track and improve performance as well as assist internal management and decision-making. The OECD provides advice on the most important applicable quantitative indicators dividing them into 3 main categories (inputs, operations, product) which follow the flow of resources within a facility (*OECD Sustainable Manufacturing Indicators - OECD*, n.d.)

Regarding the input category 3 indicators have been defined as the *non-renewable material intensity*, the *weight of restricted substances intensity* and the *recycled/reused content of material inputs*.

The *non-renewable materials intensity* is expressed in tonnes/nf and measures the non-renewable materials intensity of the facility relative to a normalisation factor of your choice. It does not include water or fuels as non-renewable materials since they are accounted in other indicators. The *weight of restricted substances intensity*, expressed in tonnes/nf, measures the use of substances restricted by law as a proportion of your production. The *recycled/reused content of material inputs* accounts for all material inputs that are to be used for manufacturing processes by weight other than fuel and water. It excludes materials recycled and reused within the facility.

Regarding the operations category the OECD defines different indicators to monitor the reduction of natural resource consumption. The first introduced is the *water intensity* that, expressed in m^3/nf, allows to assess how water is managed within a company. Although water covers over two-third of the earth's surface and is renewable on a global scale, local shortages and quality problems are frequent. Water withdrawn for industrial processes, if not returned to the same water body in its original quantity and quality, could contribute to the depletion of rivers and lakes. When water is consumed, such as when it is incorporated into beverages, it cannot easily be substituted or reduced. For that reason, the indicator calculates only the intensity of total water intake of the overhead and production process. Then, the *energy intensity* indicator, expressed in MJ/nf, is introduced to calculate energy consumption for production processes and overhead. Any energy production, whether non-renewable or renewable, depletes non-renewable resources (including habitats, fossil fuels and uranium), generates GHGs or both. Although the energy intensity of the world's production processes is constantly improving, the volume of production is increasing even faster, leading to ever-increasing levels of energy consumption. Another very important indicator consists in the *natural cover* that, expressed in % of m2, allows to evaluate the amount of soil removed from the natural environment by the plan. This is not an absolute measure of the sustainability of the facility or its products, it does indicate the percentage of land used by the facility. By providing some natural cover, it is a sign to employees and the surrounding community that environmental performance is a concern to the facility. For this indicator, natural cover can include undisturbed land as well as landscape green cover. In the case of undisturbed land, it could include natural forest, grassland, scrub or wetland.

Regarding the products category the recycled/reused content of products is introduced. Similarly, to the one introduced in the input category, here it represents the average content of recycled/reused or remanufactured materials in all products produced over the reference year.

Energy performance indicators

One of the major success factors in energy management in manufacturing industries is the implementation of effective energy performance indicators (EnPIs). This kind of indicators help identify which entity or process is more efficient under the energy point of view. This is the reason a

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growing number of manufacturing companies are developing sets of KPI, easy to calculate, that allow comparison between systems and provide historical data analysis to support decision-making processes, especially in energy-intensive companies.

According to different authors EnPIs can be divided into 3 categories: consumption, efficiency and renewability (Andersson & Thollander, 2019; May et al., 2013; Mayer et al., 2020). A complete list of energy performance indicators reviewed from literature is reported in Table 2.

Table 2: Energy performance indicators

Consumption	**Efficiency**	**Renewability**
- Specific energy consumption - Energy savings - Energy waste - Net energy indicator - Cumulative energy demand - Non-renewable energy demand - Fossil energy use - Primary fossil energy use - Secondary energy use - Energy saving potential - Total energy consumption	- Energy efficiency (1) - Energy efficiency (2) - Energy ratio - Energy intensity	- Output renewability

Regarding energy consumption indicators, in the context of the LCEA (Life Cycle Energy Assessment) (Arvidsson & Svanström, 2016; Mayer et al., 2020) propose a general framework for energy use indicator construction and reporting in LCA studies. This framework differentiates between 1) renewable and non-renewable energies, 2) primary and secondary energies, and 3) energy intended for energy purposes versus energy intended for material purposes. So, they introduced the following five energy use indicators frequently used in LCA studies.

- Cumulative Energy Demand (CED)

Rather widespread in LCEA analyses, it represents direct and indirect energy consumption throughout the product life cycle, including energy used for the extraction, manufacture and disposal of raw and auxiliary materials.

- Non-Renewable Cumulative Energy Demand (NRCED)

It is a variant of the CED indicator and it is used for the evaluation of midpoint impacts. The main difference from CED consists in the exclusion of renewable forms of energy from its calculation.

- Fossil Energy Use (FEU)

This is a rather frequent indicator in LCEA studies that allows to map the consumption of fossil energy along the entire production cycle. Where the framework (see Table 3) has an undefined coefficient (n.d.) it is to be considered variable depending on the application cases.

- Primary Fossil Energy Use (PFEU)

More defined than the previous indicator, it allows to express the primary energy consumption of a product during its entire life cycle.

- Secondary Energy Use (SEU)

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Contrary to the other indicators the SEU does not contain primary energy (see Table 3**Error! Reference source not found.**). This indicator can be considered as the sum of the energy inputs in the life cycle of the product at inventory level, as carrier of energy in the form of commodities (electricity, fuel).

These indicators allow to provide a general overview of energy consumption considering the entire life cycle of a product. They are generally expressed in MJ/kg and calculated according to the LCA methodology and based on the mathematical formula below and framework reported in Table 3.

$$I = (x_P E_P \cup x_S E_S) \cap (x_R E_R \cup x_{NR} E_{NR}) \cap (x_E E_E \cup x_M E_M)$$

Where E_P= primary energy, E_S= secondary energy, E_R= renewable energy, E_{NR}= non-renewable energy, E_E= energy intended for energy purposes (fuel, electricity), E_M= energy intended for material purposes (solvent). Xp, Xs, Xr, Xnr, Xe, Xm are the coefficients which take value 0 or 1 depending on the indicators chosen to be calculated. For example, considering Cumulative Energy Demand (CED) the calculation follows the formula below:

$$I = E_P \cap (E_R \cup E_{NR}) \cap (E_E \cup E_M)$$

The values of the coefficients used to define an energy use indicator are reported in Table 3Table 3.

Table 3: Coefficient for the calculation of energy use indicators

Coefficients	CED	NRCED	FEU	PFEU	SEU
Xp	1	1	n.d	1	0
Xs	0	0	n.d	0	1
Xr	1	0	0	0	n.d.
Xnr	1	1	n.d	n.d.	n.d.
Xe	1	1	1	1	1
Xm	1	1	n.d	n.d	n.d.

More analysis carried out by (Mayer et al., 2020) highlight how this set of indicators does not consider process losses and therefore they propose a further indicator, the Net Energy Indicator (NEI). This allows to calculate the overall losses of a process. This KPI is generally obtained through the difference between the output and the input of a system, in terms of energy content expressed in MJ/nf.

Further studies have shown a possible extension of the NEI through the introduction of more reliable and specific indicators. In the field of energy savings, (Coroiu & Chindris, 2014) (Li-Ming Wu & Bai-Sheng Chen, 2007) introduced the energy saving potential and energy savings, respectively. Both indicators allow for a quantitative assessment of the energy that could be saved. The first measures the portion of energy that could have been saved in case energy performance of the reference system were aligned with the best practices. The *energy savings* indicator (A*ppendix I*), expressed in MJ/nf, allows to measure process consumption and evaluate energy savings or overuse with respect to the designed conditions. In the context of previous studies, recent papers present a globally widespread and highly standardized indicator, known as specific energy consumption (SEC). Discussed by Li et al. (2020) it allows to measure energy consumption for a defined normalization factor, generally indicated as volume or kg of product. Being very common, it has been shown that the results can be easily comparable and used as a competitive tool for achieving both economic and environmental

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goals. (Shim & Lee, 2018)introduce important considerations regarding the corporate energy performance, focusing their study on the energy consumption indicator, used to track consumptions of the entire organization. Expressed in MJ, it has been demonstrated to be particularly useful in identifying consumption anomalies in relation to the different subsystems of a company. (Mayer et al., 2020) and Yi et al. (2020) deepen the topic of energy losses through the development of the energy waste indicator that allows the measurement of the losses of a specific production process by expressing them in MJ.

Regarding energy efficiency, the literature does not show such an abundance of proposals for new indicators. This is probably since the currently available indicators are highly standardized and constitutes a solid basis for comparison between companies. Within energy efficiency the most common metric is the energy intensity, introduced by (Coroiu & Chindris, 2014). This indicator provides a measure of the energy efficiency of a company's economic system and it is generally expressed as the ratio between MJ and the currency of the state in which the indicator is calculated, providing information about the profitability of the energy consumed.

Additional authors focus their studies at process level by identifying specific indicator to measure efficiency of production processes. In this context, (Mayer et al., 2020; Perroni et al., 2018)respectively introduce two indicators, namely energy ratio and energy efficiency. The first is used to measure the actual performance of a production process expressed in percentage terms and calculated as a ratio between output and input energy. The second provides a measure of the degree of deviation of the energy performance of a process from the ideal state and it is measured as the ratio between the actual energy consumption and ideal energy consumption, both expressed in MJ. In conclusion Sebastian Thiede, author of "energy efficiency in manufacturing system", discusses how the term energy efficiency can have different meanings depending on the context. In the context of energy efficiency in manufacturing companies, efficiency concerns the ability to produce the same amount of product while consuming less energy, thus optimizing productivity. So, the author introduces an indicator that allow to measure the yield of each MJ of energy consumed. In this case energy efficiency is calculated as the ratio between the production output, expressed in kg, m3 or units, and the total energy input in MJ.

Finally, regarding renewability indicators, (Mayer et al., 2020) explains that in manufacturing context the indicator used to calculate the renewability of a given system is generally expressed as the ratio between the energy of renewable origin in input to a system, and the energy consumed. This indicator is known as *output renewability*.

The same consideration made for the energy efficiency area in relation to the number of new indicators proposed apply to the area of energy renewability. In particular, the incidence of the intermittent nature of renewable energy sources with respect to the need for continuous energy consumption by production processes should be investigated, with repercussion on the problems of accumulation of the energy produced by these sources.

Environmental GRI indicators

As anticipated in section 0, the Global Reporting Initiative (GRI) provides a list of KPIs, divided into 5 main categories, as well as suggestions and guidance for the calculation to help companies reporting their impacts on the environment (GRI 300). It is important to highlight that some of the indicators presented in this section have already been covered above so, they have been reported here just for completeness purposes. GRI 301 addresses the topic of materials. The inputs used to manufacture and package an organization's products and services can be non-renewable materials, such as minerals, metals, oil, gas, or coal; or renewable materials, such as wood or water. Both renewable and

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non-renewable materials can be composed of virgin or recycled input materials (*Gri-301-Materials-2016*, n.d.). The standard suggests the use of the following indicators:

- *Total weight or volume of materials* that are used to produce and package the organization's primary products and services during the reporting period, identifying the ratio of renewable and non-renewable materials used (*Gri-301-Materials-2016*, n.d.).(*Gri-301-Materials-2016*).

- Percentage of *recycled input materials* used to manufacture the organization's primary products and services (*Gri-301-Materials-2016*, n.d.).This indicator is calculated as the ratio between the total recycled input materials used and the total input materials used.

Regarding GRI-302: Energy, an organization can consume energy in various forms, such as fuel, electricity, heating, cooling or steam. Energy can be self-generated or purchased from external sources and it can come from renewable sources (such as wind, hydro or solar) or from non-renewable sources (such as coal, petroleum or natural gas). Using energy more efficiently and opting for renewable energy sources is essential for combating climate change and for lowering an organization's overall environmental footprint (*Gri-302-Energy-2016*, n.d.). The following indicators are suggested to be included in the analysis.

- *Total energy consumption* within the organization, in joules or multiples, with a breakdown by the following types:

- Electricity consumption;
- Heating consumption;
- Cooling consumption;
- Steam consumption.

- *Renewable and non-renewable energy use*, with a breakdown by the following sources:

- Hydroelectric;
- Biomass;
- Solar;
- Wind;
- Solar;
- Natural Gas;
- Coal;
- Other fossil fuels.

GRI 302-2: Energy consumption outside the organization will not be considered in the DENiM framework since only direct energy consumption will be included. Regarding Energy intensity, GRI 302-3 provides guidelines on the reporting of the *energy intensity* indicator, defined as the ratio by dividing the absolute energy consumption by the organization-specific metric (or normalization factor). In combination with the organization's total energy consumption this indicator helps to contextualize the organization's efficiency, including in relation to the other organizations. For DENiM specific purposes only the intensity ratio within the organization will be considered. Lastly, GRI 302-4 communicates reporting requirements in terms of reduction of energy consumption, in fact it should be reported the amount of *reductions in energy* consumption achieved as a direct result of conservation and efficiency initiatives, excluding reduction resulting from reduced production capacity or outsourcing.

Another important aspect treated by GRI concerns water consumption (GRI 303) since access fresh water is essential for human life and wellbeing, and is recognized by the United Nations as a human right. An organization can impact water resources through its withdrawal and consumption of water (*Gri-302-Energy-2016*, n.d.; *Gri-303-Water-2016*, n.d.). Disclosure 303-1 analyse water withdrawal suggesting of the *total volume of water withdrawn*, with a breakdown by the following sources:

- Surface water (wetlands, rivers, lakes and oceans);
- Ground water;
- Rainwater stored by the organisation;
- Wastewater from another organisation;
- Municipal water.

Reporting the total water withdrawal contributes to an understanding of the overall potential impacts associated with the organization's water use. Furthermore, it gives an indication of the organization's relative size and importance as a user of water providing a baseline for other calculations relating to efficiency and use. GRI 303-3 provides guidelines on the reporting of the *total volume of water recycled and reused* by the organization. The rate of water reuse and recycling is a measure of efficiency and demonstrates the success of an organization in reducing total water withdrawals and discharges. Increased reuse and recycling can reduce water consumption, treatment, and disposal costs. Reducing water consumption over time through reuse and recycling also contributes to local, national, or regional goals for managing water supplies.

In the same context, GRI 303 helps understand how an organization manages water-related impacts. A company can reduce its water withdrawal, consumption, discharge, and associated impacts through efficiency measures, such as water recycling and reuse, and process redesign, as well as through collective actions that extend beyond its operations within the catchment. It can improve water quality through better treatment of water discharge. GRI 303-4: Water discharge suggests the use of total water discharge and a breakdown by the following types of destination (*Gri-303-Water-and-Effluents-2018*, n.d.)

- Surface water (wetlands, rivers, lakes and oceans)
- Ground water
- Seawater
- Third-party water

Also, for each destination the *percentage of fresh water*(≤1,000 mg/L Total Dissolved Solids) and *other water*(≤1,000 mg/L Total Dissolved Solids).

GRI 305 discuss the topic of emissions in air, which are the discharge of substances from a source into the atmosphere. According to the standard, the total emissions, expressed in kg, is broken down into its composition considering the following types of emissions (*Gri-305-Emissions-2016*, n.d.-a).

- Acidifying substances;
- Gases affecting climate change (GHG);
- Gases affecting ozone depletion (ODS);
- Persistent organic pollutants (POP);
- Volatile organic compounds (VOC);
- Hazardous air pollutants (HAP);

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- Particulate matter (PM).

GRI 306 addresses the topic of waste. They can be generated in the organization’s own activities, for example, during the production of its products and delivery of services. Waste can have significant negative impacts on the environment and human health when inadequately managed (*Gri-306-Waste-2020*, n.d.)These impacts often extend beyond locations where waste is generated and discarded. The resources and materials contained in waste that is incinerated or landfilled are lost to future use, which accelerates their depletion. GRI 306-3: waste generated, suggest the reporting of the *total weight of waste generated* in metric tons, and a breakdown of this total by composition of the waste (plastic, paper, metals…). GRI 306-4: waste diverted from disposal introduce 3 recovery operation (preparation for reuse, recycling, and other recovery operations) and for each the calculation of the percentage of hazardous and non-hazardous waste diverted from disposal, as well as waste recovered onsite/offsite. Following the same principle, GRI 306-5 divides waste directed to disposal into the following disposal operations.

- Incineration (with energy recovery);
- Incineration (without energy recovery);
- Landfilling;
- Other disposal operations.

For each operation the percentage of hazardous and non-hazardous waste has to be reported as well as the composition of waste disposed onsite/offsite. Reporting the quantity and type of waste directed to disposal onsite and offsite shows the extent to which the organization knows how its waste is managed.

In conclusion, GRI 307 addresses the topic of environmental compliance, covering organization’s compliance with environmental laws and/or regulations, while GRI 308 addresses the topic of supplier environmental assessment. The first has not been used since fines and non-monetary sanctions for non-compliance with environmental law are not significative to DENiM, the second, regarding supplier environmental assessment will not be considered in the final framework since only direct environmental impacts will be included.

Social performance indicators

Social responsibility has become an important concern for companies and organization all over the world. Nevertheless, widespread standards related to a company social impact remain scarce, especially in manufacturing. This can be probably attributed to the difficulty of finding metrics that are comparable and quantifiable. However, based on the paper analysed a review of social indicators has been carried out and according to (Hristov & Chirico, 2019) these indicators can be classified into the dimensions reported in Table 4.

Table 4: Social performance indicators

Employees acceptance of organizational change	**To guarantee the quality of environmental and work condition**	**To guarantee the respect of the human rights**	**To participate at the social initiative and to maintain a high level of responsibility**
- Rate of employees that are shareholders	- Accident rate	- equality rate - labour intensity	- % participants in social initiatives

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- Employee satisfaction rate - Employee turnover rate	- Time of employees working in dangerous workplaces - Noise level - Absenteeism		

Social sustainability represents the capacity of providing for citizen’s welfare with equal distribution among classes and genders. Regarding employees acceptance of organizational changes, (Winroth et al., 2012)introduced two indicators for continuous monitoring social performance within a company. The first is defined as the *rate of employees that are shareholders* which is important to understand how much the employees believe in the organization. The second helps evaluate the internal job satisfaction and it is known as *employee satisfaction rate*. They also explain how this kind of KPI is not calculable by a direct formula but rather with an internal questionnaire. More analysis carried out by (Dočekalová & Kocmanová, 2016) explain how, under certain conditions, the *employee turnover rate* could help understand the satisfaction of workers.

To guarantee the quality of environmental and working condition (Akbar & Irohara, 2018) introduce three indicators. The first allows to quantify the noise level in terms of decibel (db), to identify workplaces or spots to investigate in order to safeguard safety of the workers. Then, they suggest monitoring absenteeism in terms of % of days of absence over the total number of working days. The third is known as accident rate and helps identify the number of accidents within a given period, so to define any dangerous workplaces. More analysis carried out by (Zarte et al., 2019) also suggest considering the time of employees working at risky workplace, expressed in hours, as an indicator to help improving safeguard of workers.

Regarding the respect of human rights. (Dočekalová & Kocmanová, 2016) and introduce the gender equality rate, discussing the importance of a balance male to female ratio. (Linke et al., 2013) introduce the labor intensity indicator which accounts for the number of workers hours needed per normalization factor. They explain that this indicator could be adapted depending on the company strategy, for example by assessing the educational level of workers per task. Finally, with respect to last category related to social initiatives and high level of responsibility (Hristov & Chirico, 2019) explain the importance of social actions suggesting to monitor the number of initiatives at national and local level, the total expenses for social initiatives and the % of participants in social initiatives. In the same context, the Global Reporting Initiative (GRI) has defined a set of guidelines and indicators to help organization understand and communicate their social impact. In terms of social performance, the GRI has divided the proposed set of indicators into several aspects, suggesting at least one indicator for each aspect (Sampong et al., 2018). Table 5 reports the indicators according to GRI guidelines.

Table 5: GRI guidelines for social performance indicators

Aspect	**Indicator code**[1]	**Description**	**Unit**
Employment	LA1	Total workforce by employment type, employment contract, and region, broken down by gender	#
	LA2	Total number and rate of new employee hires and employee turnover by age group, gender, and region	#

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[1] The code is defined according to GRI 3.1 guidelines https://www.mas-business.com/docs/G3.1-Guidelines-Incl-Technical-Protocol.pdf

	LA3	Benefits provided to full-time employees that are not provided to temporary or part-time employees, by significant locations of operation	-
	LA15	Return to work and retention rates after parental leave, by gender	%
Labor/Management Relations	LA4	Percentage of employees covered by collective bargaining agreements	%
	LA5	Minimum notice period (s) regarding operational changes, including whether it is specified in collective agreements	Weeks
Occupational Health and Safety	LA6	Percentage of total workforce represented informal joint management– worker health and safety committees that help monitor and advice on occupational health and safety programs	%
	LA7	Rates of injury, occupational diseases, lost days, and absenteeism, and total number of work-related fatalities, by region and by gender	#
	LA8	Education, training, counselling, prevention, and risk-control programs in place to assist workforce members, their families, or community members regarding serious diseases	#
	LA9	Health and safety topics covered in formal agreements with trade unions	#
Training and Education	LA10	Average hours of training per year per employee by gender, and by employee category	Hours
	LA11	Programs for skills management and lifelong learning that support the continued employability of employees and assist them in managing career endings	#
	LA12	Percentage of employees receiving regular performance and career development reviews, by gender	%
Diversity and Equal Opportunity	LA13	Composition of governance bodies and breakdown of employees per employee category according to gender, age group, minority group membership, and other indicators of diversity	-
Equal Remuneration for Women and Men	LA14	Ratio of basic salary and remuneration of women to men by employee category, by significant locations of operation	%

3.3.2 Impact indicators

As previously mentioned, inventory indicators do not provide any information about impacts on the environment, so during the Life Cycle Impact Assessment (LCIA) phase, inventory data are assigned to mid-point categories and then converted into impacts on the environment according to the characterization models selected. Since the wide availability of characterization methodologies concerning the LCIA, the next section provides an overview of currently adopted impact indicators focusing on the ones proposed by PEF, OEF and EPD that could operate as a standard in the not already standardized impact category selection of LCA.

Environmental Footprint (OEF) / Product Environmental Footprint (PEF) indicators

Following the principles of LCA, presented in section 3.1.1, during Life Cycle Impact Assessment (LCIA) resource use and emissions, gathered during Life Cycle Inventory (LCI), are translated into potential impacts on the environment. According to Product Environmental Footprint (PEF) (Manfredi et al., 2012) and Organisation Environmental Footprint (OEF)(Pelletier et al., 2012) the aim of these methodologies is to provide measurement and improvement tools designed to help assess the environmental performance of products/services/organisations across their life-cycle (*PEF and OEF: Assessment of Environmental Performance of Products, Services and Organisations - IMQ*, n.d.). A list of 16 midpoint impact indicators has been identified (Table 6), and only these will be included in the analysis. In fact, while endpoint indicators (e.g. human health impacts) are easier to apply in decision-making, they calculate potential impacts further down the cause-and-effect chain and are typically more uncertain and/or subjective. Each indicator is presented using a unique unit (e.g. kg CO_2 equivalent for global warming potential) and all the relevant flows are normalised to a single unit using characterization factors in order to understand likely environmental impacts (*LCIA Recommended Indicators - The Life Cycle Association of New Zealand*, n.d.).

Another important program is the Environmental Product Declarations (EPD) which is an independently verified registered document that communicates transparent and comparable information about the life-cycle environmental impact in a credible way (*EPD International*, n.d.). The EPD provides a default list of 7 indicators (Table 7) and methods that help assessing the environmental performance of a product from a life cycle point of view. The results of the LCA study are communicated according to the Product Category Rules (PCR), which are a set of rules, requirements and guidelines for developing EPD for one or more product categories.

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Table 6: PEF and OEF environmental impact indicators

Impact category	Impact category indicator	Unit	Characterization model
Climate change, total	Radiative forcing as global warming potential (GWP100)	kg CO2 eq.	Baseline model of 100 years of the IPCC (based on IPCC 2013)
Ozone depletion	depletion	kg CFC-11 eq.	Steady-state ODPs as in (WMO 2014 + integrations)
Human toxicity, cancer	Comparative Toxic Unit for humans (CTUh)	CTUh	USEtox model 2.1 (Fankte et al, 2017)
Human toxicity, non-cancer	Comparative Toxic Unit for humans (CTUh)	CTUh	USEtox model 2.1 (Fankte et al, 2017)
Particulate matter	Impact on human health	disease incidence	PM method recomended by UNEP (UNEP 2016)
Ionising radiation, human health	Human exposure efficiency relative to U235	kBq U235 eq.	Human health effect model as developed by Dreicer et al. 1995 (Frischknecht et al, 2000)
Photochemical ozone formation, human health	Tropospheric ozone concentration increase	kg NMVOC eq.	LOTOS-EUROS model (Van Zelm et al, 2008) as implemented in ReCiPe 2008
Acidification	Accumulated Exceedance (AE)	mol H+ eq.	Accumulated Exceedance (Seppälä et al. 2006, Posch et al, 2008)
Eutrophication, terrestrial	Accumulated Exceedance (AE)	mol N eq.	Accumulated Exceedance (Seppälä et al. 2006, Posch et al, 2008)
Eutrophication, freshwater	Fraction of nutrients reaching freshwater end compartment (P)	kg P eq.	EUTREND model (Struijs et al, 2009) as implemented in ReCiPe
Eutrophication, marine	Fraction of nutrients reaching marine end compartment (N)	kg N eq.	EUTREND model (Struijs et al, 2009) as implemented in ReCiPe
Ecotoxicity, freshwater	Comparative Toxic Unit for ecosystems (CTUe)	CTUe	USEtox model 2.1 (Fankte et al, 2017)
Land use	Soil quality index 3) Biotic production Erosion resistance Mechanical filtration Groundwater replenishment	Dimensionless (pt) kg biotic production kg soil m^3 water m^3 groundwater	Soil quality index based on LANCA (Beck et al. 2010 and Bos et al. 2016)
Water use	User deprivation potential (deprivation-weighted water consumption)	m^3 H_2O eq.	Available WAter REmaining (AWARE) as recommended by UNEP, 2016
Resource use, minerals and metals	Abiotic resource depletion (ADP ultimate reserves)	kg Sb eq.	CML 2002 (Guinée et al., 2002) and van Oers et al. 2002.
Resource use, fossils	Abiotic resource depletion – fossil fuels (ADP-fossil)26	MJ	CML 2002 (Guinée et al., 2002) and van Oers et al. 2002

Table 7: EPD environmental impact indicators

Impact category	Impact category indicator	Unit	Characterization model
Climate change, total	Global Warming Potential	kg CO_2 eq.	GWP100, CML 2001 baseline
Photochemical ozone formation, human health	Photochemical oxidant formation potential	kg NMVOC eq.	POFP, LOTOS-EUROS as applied in ReCiPe 2008
Acidification	Accumulated potential	kg SO_2 eq.	AP, CML 2001 non-baseline (fate not included)
Eutrophication, freshwater	Eutrophication potential	kg PO43- eq.	EP, CML 2001 baseline
Water use	Water Scarcity Footprint (WSF)	m^3 H_2O eq.	AWARE Method: WULCA Recommendations on characterization model for WSF 2015, 2017
Resource use, minerals and metals	Abiotic depletion potential – Elements	kg Sb eq.	ADPelements, CML 2001, baseline
Resource use, fossils	Abiotic depletion potential – Fossil fuels	MJ	ADPfossil fuels, CML 2001, baseline

3.3.3 Economic performance and cost indicators

To know how well businesses are performing against the objectives, a wide range of financial indicators are employed in companies. For example, profitability, solvency, liquidity and stability related indicators (Elwin & Hirst, 2007). Lately, there has been a growing interest in seeking to arrive at "win-win" situations where economic performance and sustainable development are advanced simultaneously. This formulation assumes that sustainability, which includes an economic viewpoint, must be confronted with ecologically and socially sustainable performance (Boons et al., 2013).

According to (Kocmanova et al., 2017a), the financial and cost indicators reviewed from the literature can be divided into various categories (Table 8**Error! Reference source not found.**). It should be noted that the indicators can be used both for financial reporting (particularly financial accounting e.g. annual and sustainability reports) and for supporting internal development and decision-making (particularly cost / management accounting). The table also gives the overview of the indicators which support judging and decision making with respect to economic and cost impacts of industrial energy management and the cost savings potential related to energy efficient production and production assets (for formulas, see A*ppendix I*).

Table 8: Economic performance indicators adapted from (Kocmanova et al., 2017b)

Profitability
Return of equity (ROE), Return on assets (ROA), Return on sale (ROS), Return on capital employed (ROCE), Return on Investment (ROI), Net Present Value (NPV), Present Value of Costs (PVC), Internal Rate of return IRR (%), Pay Back Period (years), Discounted Pay Back Period (years) etc.
Cost
Total life cycle costs and cost savings (LCC), CAPEX, OPEX, Lost revenue through production losses etc.
Financial stability
Liquidity, Debt, Production assets turnover, Employee turnover, Inventory turnover, Net profit margin, Total cost of ownership, Investments, Risk appetite and tolerance etc.
Operational efficiency
Productivity, Delivery precision, OEE (overall Equipment effectiveness: availability, performance, quality) etc.
Market position and competitiveness
% of money for the purchase from local suppliers, number of customers, customer satisfaction & retention, market demand and growth, market share, competitiveness situation, legislation changes, investments in environmental certification (ISO 9001, ISO 14001, ISO 50001, UNE 166002 and OHSAS 18001)

(Kocmanova et al., 2017b) introduced a first set of KPIs concerning the profitability aspect. Rather widespread these indicators are known as ROE, ROA, ROS and ROCE. *Return On Equity (ROE)* shows how good a company is generating returns on the investments received from its shareholders. *Return On Assets* is an indicator that provides how much a company is able to generate from its assets. So, it measures how efficient a company's management is in generating earning from their economic resources or assets on their balance sheet. *Return on Sales* is a ratio used to evaluate a company's operational efficiency. This indicator shows how much is being produced per currency of sales. Finally, the Return On Capital Employed (ROCE) indicator is introduced and it consists of a financial ratio used in assessing a company's capital efficiency. This ratio help understand how a company is generating profits from its capital.

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Regarding financial stability the same authors discuss two important indicators known as *liquidity* and *debt*. Liquidity refers to the ease an asset can be converted into cash without affecting its market price, while debt is defined as the amount of money borrowed for making large purchase not affordable under normal circumstances. In the same context, (Dočekalová & Kocmanová, 2016) introduce two important indicators. The *asset turnover* indicator which measures the value of a company's sales relative to the value of its assets, usually during a year, and the *inventory turnover* which is defined as a ratio that shows how many times a company has sold and replace its inventory during a given period.

More analyses carried out by (Akbar & Irohara, 2018) identify the *net profit margin*, which is defined as how much net income or profit is generated as a percentage of revenue and it is calculated as below. (Hristov & Chirico, 2019) highlight the importance of the *total cost of ownership* indicator. Defined as the purchase price of an asset plus the costs of operation, it helps companies in purchasing decision in long-term scenario.

The third category introduced by (Kocmanova et al., 2017c) refers to economic operations and the same authors introduce the concept of productivity. This indicator captures the performance of a company in relation to the total revenues. Research carried out by (Winroth et al., 2012) introduces the delivery precision that, measured in % of in time delivery, is a very important indicator that companies are currently monitoring because it directly affects customers satisfaction.

Regarding the market position category, the authors introduce the % of money for the purchase from local suppliers defined as the percentage of money for the purchase of material and services from local suppliers. Finally, in recent research (Hristov & Chirico, 2019) introduce the concept of labels that suggesting to consider the amount of money spent in investment in environmental certification. The issue of environmental sustainability is certainly linked to the economic one since companies aim to reduce impacts without increasing production costs. So, companies are becoming increasingly aware of the importance of sustainable production and the communication related to products. In fact, the measurement and communication of environmental performance have become essential to be competitive on the market. This is the reason for the development of several standards in order to regulate environmental declarations (ISO 9001, ISO 14001, ISO 50001, UNE 166002 and OHSAS 18001).

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4 Introduction to technological requirements and demonstration scenarios to support LCA & LCCA framework

In order to have a clear understanding of how the KPI framework had to be designed, it was necessary to (i) take into consideration the tools and technologies that will be adopting the indicators and (ii) understand the current situation in terms of KPIs usage and the possibility of data acquisition and elaboration before and after the DENiM project by the pilots. To this end, in the following chapter these two activities have been carried out by working together with the task leaders in understanding the objectives and needs of the tools adopting the KPI framework and, in parallel, organising workshops with industrial pilots, to collect input requirements for its refinement. The two activities are briefly discussed hereinafter.

4.1 Technologies and tools adopted in the DENiM framework for data acquisition and elaboration

The DENiM project integrates several technologies and tools that enable the exchange and processing of data. In this chapter, according to the official nomenclature, the different tools are divided into four functional groups: Digital Integration (DI), Digital Twin (DT), Decision Support System (DSS), Digital Skills (DS).
Online Lifecycle Analysis (LCA), Online Lifecycle Cost Analysis (LCCA) and Energy sustainability label are the tools involved, while LCA and LCCA analyses are performed using two online tools that receive input from upstream tools and specifications/parameters defined in the previous chapters. The following Figure 6: Summary of main interactions regarding LCA and LCCA provides an overview of the main inputs and outputs regarding data and the primary connection between tools involved.

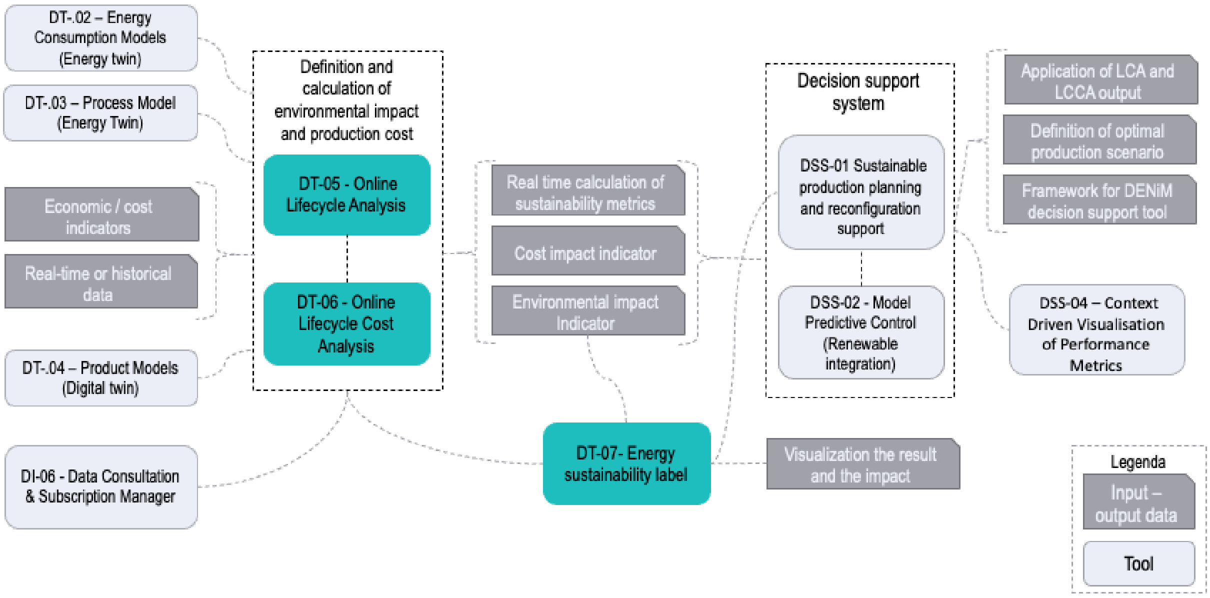

Figure 6: Summary of main interactions regarding LCA and LCCA tools

Online Lifecycle Analysis tool and Life Cycle Cost Analysis tool

The online Lifecycle Analysis (LCA) tool provides the emission and environmental impacts model thanks to the integration with the Digital Twin and Energy Twin tools and the access to real-time and historical data from pilots. The integration with Data Consultation & Subscription Management tool is a crucial feature in order to correct access and use data coming from pilots. The tool for online Life Cycle Cost Analysis (LCCA) assesses the life cycle costs associated with the production process. Overall,

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the “LCA and LCC calculation view” can be defined as a user interaction component and it provides a dashboard for the tool users. In DENiM Task.5.4 (LCA) and Task 5.5 (LCCA) starting at M10 following the DENiM architectural and other technology-related requirements (WP4, WP6 and WP7), and it will be applied in WP8 (Pilot tasks) to make the assessments procedure usable practice. The output coming from LCA and LCCA online tools are closely linked to decision support tools and visualisations tools. The environmental impact indicators calculated in the LCA tool provides the basis for the decision support system and specifically for the production planning and reconfiguration tool (DSS-01). The cost calculated indicators support the decision-makers in degerming and selecting the most cost-effective option among different alternatives, and, at the same time satisfying the technical, environmental, operational, health, safety and regulatory requirements. In addition, the Energy performance indicators tools, strictly linked with LCA output, allow the visualisation of environmental impact indicators and creation of sustainability-related labels using different “registers” according to the interested stakeholder and objectives, with the final aim to support the enhancement of the sustainability performance.

4.2 Introduction to LCA and LCCA in the DENiM pilots

The main objective of this paragraph is to better understand the state of the pilot in terms of Life Cycle Assessment (LCA) and Life Cycle Costing analysis (LCCA) data availability, acquisition and elaboration. In order to set the basis for the sustainability framework, the inputs coming from the pilots have been analysed so to better understand the starting point for each of them. An excel sheet (see from Appendix II to A*ppendix XI*) has been circulated with the aim of first gathering more information regarding LCA & LCCA activities and second identify already measured indicators to be further inspected in the framework. In particular, the pilots have been asked for a mapping of the currently measured indicators as well as the environmental assessment methods and tools currently used. This was very helpful to set basis for the workshops with the pilots which have been held starting April 13th, 2021.

The main objective of the workshops was to start setting the scene for the environmental and cost framework on the top of which the DENiM platform will rely for energy-oriented optimisation. To facilitate the discussion an online MURAL board has been used. The workshops featured two main moments: the first one dedicated to the introduction of the pilot as well as the presentation of the theoretical background of LCA and LCC methodologies; the second one focused on the discussion of the framing conditions that helped understanding pilots’ LCA-LCC current situation, and highlight the gaps to be covered to implement and/or improve LCA-LCC analysis. Each workshop was organized differently from the others so to focus the discussion on the points of greatest interest according to the answers and information provided through the excel file and pilot specification document. Then, the results have been elaborated with the aim of defining the focus objective for each pilot according to the predefined targets.

For each pilot a description of the As-Is State as well as the results analysis of the workshop is provided in the paragraphs below.

4.2.1 Pilot 1: DePuy Synthes – Cork, Ireland

Digitisation to support sustainable production planning and maximising the use of renewable energy
Background
As a medical device manufacturer, DePuy Synthes is mindful of their impact on the environment and the facilities in Cork, Ireland have received Johnson & Johnson Sustainability Awards for their

This project has received funding from the European Union’s Horizon 2020 research and innovation program under grant agreement No 958339.

environmental leadership. However, there is still potential to further improve energy-efficiency and ensure it is considered holistically across a specific value chain. DePuy Synthes Cork consumed over 56,000 MWh in 2019 with production responsible for almost 40% of this figure.

Product/process description

Product: Polymer (UHMWPE) Attune Knee inserts.
The target Poly value stream production processes which define the boundaries of LCA and LCCA are reported below in Figure 7.

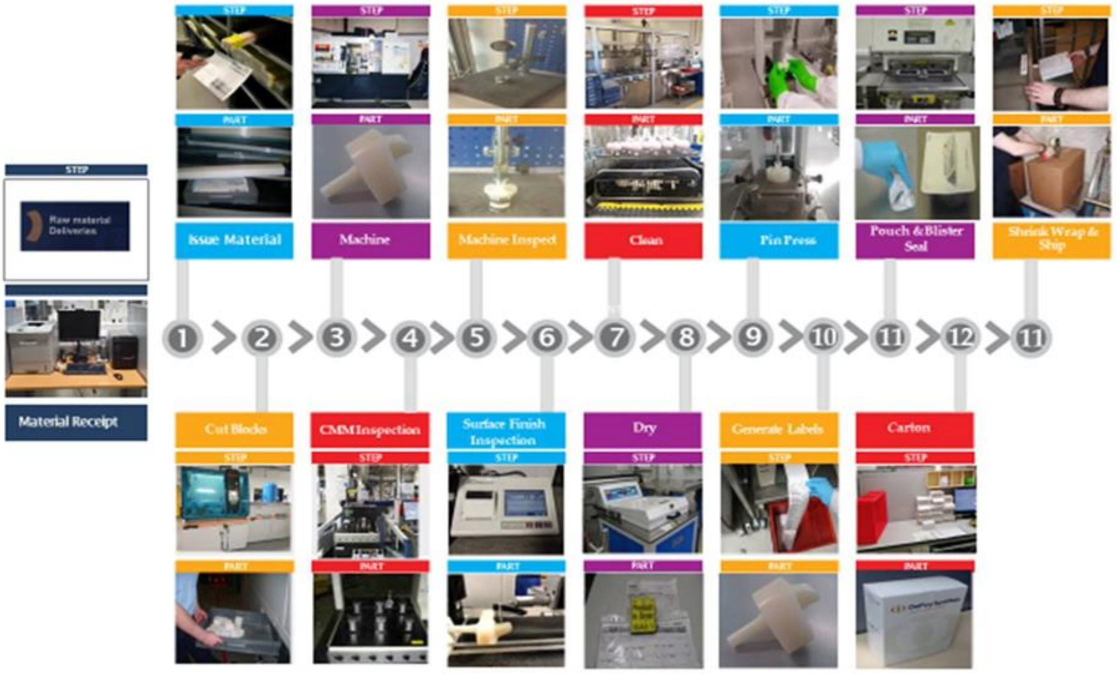

Figure 7: DePuy Synthes Poly value stream production processes

Main objectives

The main objectives of the company within the DENiM project are defined as follows:

- Increase the monitoring of assets associated with the poly process
- Provide capabilities to visual asset energy use in "real-time"
- Enable fault detection and diagnosis on key assets
- Identify opportunities to reduce scrap production
- DENiM Platform to be deployed and operational within Poly VS by June 2024
- 35% reduction in Poly VS asset energy costs
- 10% Reduction in Costs due to scrap
- 85% (~113) Poly VS assets connected to DENiM platform
- Up to 40% (~53) Poly VS assets equipped with FDD capability via DENiM
- Integration of DENiM data into DPS Analytics hub dashboard
- Skills gap assessments performed and training programme developed

Current challenges

At the moment, DePuy is facing challenges such as the limited monitoring of asset data from an energy perspective, significant gap in existing energy performance data and weak understanding of production energy impacts at value stream level. The factory is located in two buildings. Current stage:

- No asset energy data collected
- No means to visualise asset energy use
- No FDD capabilities

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 958339.

- CNC Machines running with significant idling time - €45,000 in energy costs 2019
- Skills gaps with respect to energy use in a manufacturing environment
- Energy use not considered when bringing in new assets

Current practice

In terms of current practice for onsite energy management, DePuy is certified with ISO 50001 and few targets has been set for the reduction of CO_2 emissions in the coming years. In particular, the company will have 100% of electricity needs from renewable sources by 2025 in order to reduce carbon footprint by 25% by 2030. Several LCA/LCC projects are ongoing at DePuy but in a too early phase so no LCA/LCC tool in use yet.

Sensors and monitoring

DePuy has already some meters installed to collect data from assets but more sensors will be required to establish asset level energy consumption.

LCA knowledge

Regarding LCA knowledge, DePuy does not formally use any LCA tool to assess any existing production or manufacturing processes. According to the sensors already installed the following LCI data are available for the poly value stream: production level consumption, material input, parts produced and scraps. These data are all available in digital format.

LCC knowledge

Life Cycle Cost analysis will be conducted at process and sub-process level. Assessment on a process level would cover the Poly value stream, assessing costs associated with energy consumption and determining if savings can be made by aligning production activity with availability of renewable electricity. It would also facilitate assessment of the impact that projects happening in parallel may incur from an energy perspective. CAPEX and OPEX structure are already defined.

The Poly manufacturing process can be broken down into sub processes including material block cutting, CNC machining, laser marking, cleaning (industrial clean line) and packaging. It would be valuable to conduct LCCA on the CNC machining and the cleaning processes individually as these are present in the manufacturing of each product but will vary moderately (cycle times, process steps, etc) for each product.

Investment assessment is conducted through project portfolio reviews carried out within individual departments. Project value is assessed through projected revenue and savings incurred during and after project execution versus CAPEX and OPEX costs to establish feasibility, initiate and execute the project. This is managed through the franchise project management platform, Planisware.

CAPEX: TBD

OPEX:

- Electricity (value stream level)
- Water consumption
- Waste
- Raw material
- Consumables
- Operations personnel
- Production throughput
- OEE (uptime / downtime) cost

DePuy workshop

LCA & LCC workshop

In the first section the description of the pilot as well as the main objectives have been addressed with the aim of identifying the relevant variables to be considered in LCA and LCC analysis.

Figure 8: DePuy Mural board – LCA&LCC oriented objectives and targets

J&J has experience on LCA, but in DePuy no tools are available and no studies have been carried out yet. LCA focus and main objectives will be based on the poly value stream, assessing cost associated to energy consumption. Probably not beyond because of complexity reasons. The poly value stream will be broken down into sub-processes.

In the second section, LCA experience and LCI data gathering have been discussed. According to the answers given in the first excel file circulated through the pilots (see Appendix II), DePuy already measures lots of indicators and different methodologies are adopted. So, during the workshop the already given information have been deepen with the aim of setting the scene for both LCA and LCCA.

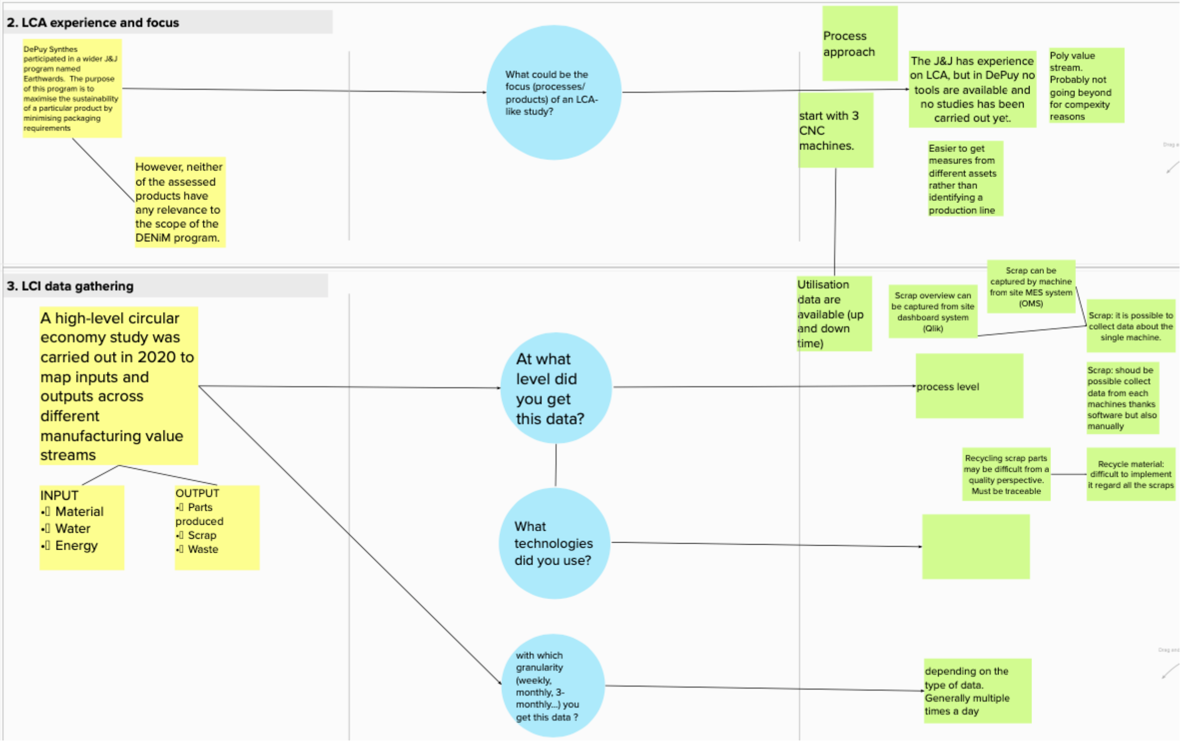

Figure 9: DePuy Mural board – LCA experience and LCI data gathering

In DePuy LCA will be based on a process approach starting with the sensing of 3 CNC machines. More relevant machines connected to this one will be identified and included in the analysis. It is

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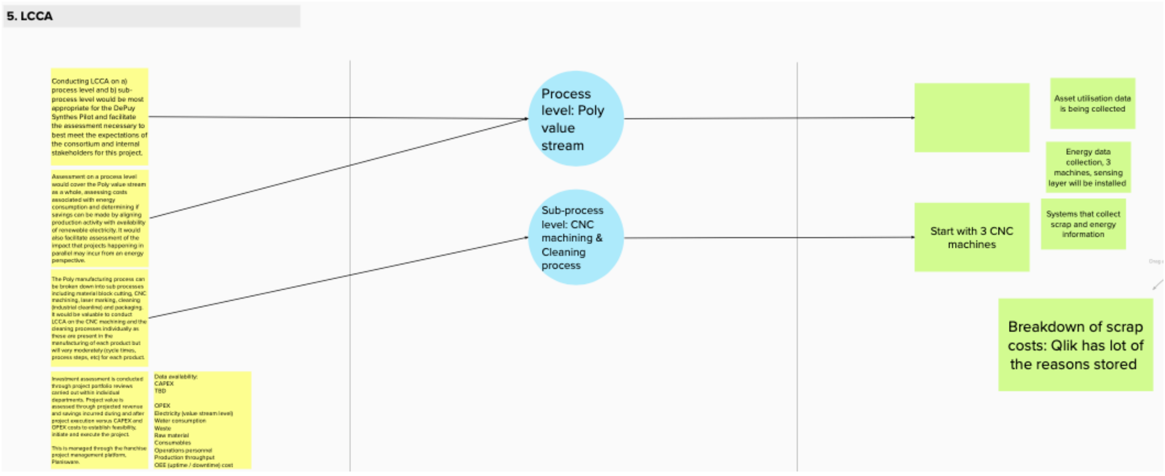
easier to get data directly from different assets rather than from a production line. Regarding LCI data inputs (materials, water, and energy usage) and outputs (scrap, wastes and parts produced) data are already available in a digital format at process level. Scrap can be captured by machine from site MES (OMS). Also, the recycling of scraps may be difficult to be implemented. Utilisation data (up and down time) of machines is already collected and available in a digital format. Regarding the granularity, DePuy can take LCI data multiple times a day.

Similarly, in the third section the main points that focus LCCA are reported to better understand the boundaries of the LCC analysis, so the entities to be considered.



Conducting LCCA on a) process level and b) sub-process level would be most appropriate for the DePuy Synthes Pilot and facilitate the assessment necessary to best meet the expectations of the consortium and internal stakeholders for this project.

Assessment on a process level would cover the Poly value stream as a whole, assessing costs associated with energy consumption and determining if savings can be made by aligning production activity with availability of renewable electricity. It would also facilitate assessment of the impact that projects happening in parallel may incur from an energy perspective.

The Poly manufacturing process can be broken down into sub processes including material block cutting, CNC machining, laser marking, cleaning (industrial cleanline) and packaging. It would be valuable to conduct LCCA on the CNC machining and the cleaning processes individually as these are present in the manufacturing of each product but will vary moderately (cycle times, process steps, etc) for each product.

Investment assessment is conducted through project portfolio reviews carried out within individual departments. Project value is assessed through projected revenue and savings incurred during and after project execution versus CAPEX and OPEX costs to establish feasibility, initiate and execute the project.

This is managed through the franchise project management platform, Planisware.

Data availability:
CAPEX
TBD

OPEX
Electricity (value stream level)
Water consumption
Waste
Raw material
Consumables
Operations personnel
Production throughput
OEE (uptime / downtime) cost

Asset utilisation data is being collected

Energy data collection, 3 machines, sensing layer will be installed

Start with 3 CNC machines

Systems that collect scrap and energy information

Breakdown of scrap costs: Qlik has lot of the reasons stored

Figure 10: DePuy Mural board – Life Cycle Costing

The main outputs of this section are reported in the following bullet points:

- At process level LCCA will consider the poly manufacturing process breaking down its structure into sub-process, including material block cutting, CNC machining, laser marking, cleaning and packaging.
- At sub-process level LCCA will consider CNC machining and the cleaning as these are present in the manufacturing of each product.
- Cost structure CAPEX (TBD) and OPEX (already provided and data are collected).

A production cost allocation system is available on machine level.

Next steps

In DePuy there will be the need to verify if it is possible to gather information on scraps production on the single machines and to investigate the machines to be included in the analysis in addition to the 3 CNC machines already identified.

4.2.2 Pilot 2: Sidenor / CIE Galfor – Spain

Reduction of environmental footprint of a crankshaft production by energy-efficient steelmaking and forging processes management

Background

The automotive sector has improved its energy consumption from 43.5 MWh/year in 2005, to the 38.8 MWh/year utilised in 2018, resulting in a 10.8 % reduction. Nonetheless, further improvements in both energy consumption and environmental impact should be still made, at both the vehicle

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and industrial levels. Considering the size of steel industry, the energy reductions achieved within DENiM will enable a significant impact on the overall industrial energy consumption in Europe.

Product/process description

Product: Crankshaft for automotive industry. Production phases: steelmaking at Sidenor and forging at CIE Galfor.
The processes involved in this pilot comprise the following installations from Sidenor and CIE Galfor (see Figure 11).

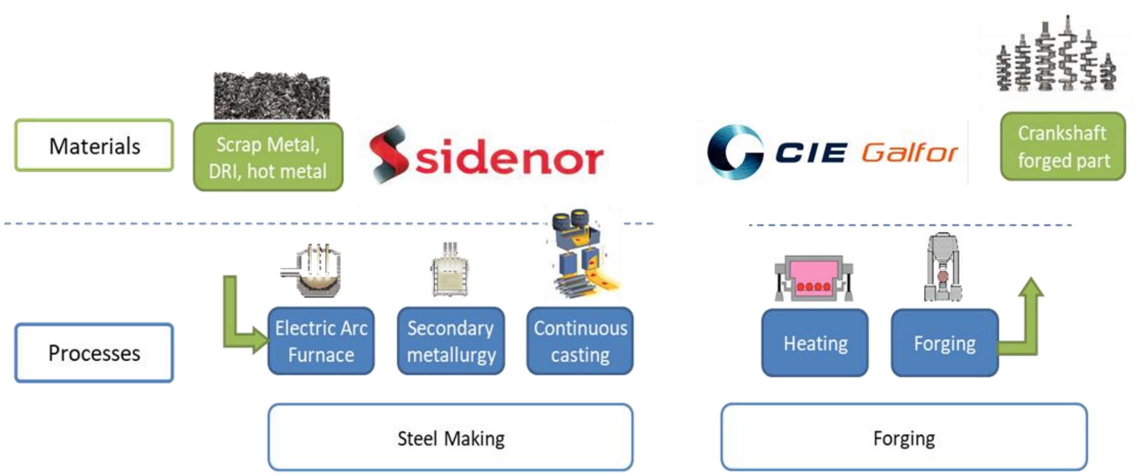


Figure 11: Processes and installations addressed in the crankshaft production pilot

Main objectives

The main objectives of the company within the DENiM project are defined as follows:

- Increase the monitoring of environmental impact of the production of a crankshaft for the automotive sector.
- Optimise the electrical energy consumption in the EAF steel melting process, by increasing its efficiency on thermal energy provided to the raw material (scrap) while ensuring product quality.
- Optimise the electrical energy consumption of the induction heating furnace used for heating the billets at the forging temperature, by getting an accurate and homogeneous thermal distribution inside the billets.
- Increase awareness of energy efficiency within the manufacturing environment and provide upskilling and knowledge sharing as appropriate.

Current challenges

Currently there is a limited exploitation of available data from an energy perspective as well as a limited collection of influential variables. So, some data are gathered manually and human errors are expected.

Current practice

Currently SIDENOR is monitoring energy consumptions and the LCA is evaluated at SIDENOR based on historic data and average values (for EPD reporting). There is a need to perform this analysis with real on-line data in order to improve the accuracy of the impacts. CIE GALFOR is currently monitoring energy consumption but has not any LCA tool of the process. Several specific energy consumptions can be measured depending on the mass of material chosen as reference (denominator).

Sensors and monitoring

Both at Sidenor and CIE Galfor it will not be necessary to install new sensors. At the moment, PLCs are used to collect variables which, however, are not used for process control and optimization.

LCA knowledge

Regarding LCA knowledge, in Sidenor the Life Cycle Assessment procedure began in 2018, following the requirements of the ISO 14040 and ISO 14044 standards.

In 2019, a working procedure and certified internal management system following the requirements of ISO 14025 standard was developed, that covers the tasks for the development of LCA and verification of Environmental Product Declarations of special steel products, according to the requirements of the Product Category Rules of the International EPD System "PCR 2015: 03 Basic iron or steel products & special steels, except construction products ". The intention is to also link the energy use and GWP (global warming potential) in products.

In CIE Galfor, in a previous pilot project, an Excel file was developed to get the carbon footprint of a single part based on the gross/weight of the part, but without taking into account in the calculation the specific production process.

Currently CIE Galfor is collecting consumption data and registering them in the ERP (SAP) in order to get the annual footprint of the whole plant.

The following data are currently being collected:

1. Materials (steel), ancillary materials (graphite, oil, …): every 3 months
2. Energy (electricity, natural gas, diesel): monthly
3. Gas (compressed air, cooling gases, …): every 3 months
4. Water: monthly
5. Waste: every 6 months

Some of these data (raw material, energy, graphite) can be collected specifically assigned to DENIM production line, while others (water, waste, compressed air) can only be assigned to the specific line in as estimated way.

LCC knowledge

There is a need to assess life cycle costs and cost savings of DENiM developments:

b) on a sub-process level (sub-process LCC)

- For **Sidenor**: Melting process at the Electric Arc Furnace
- For **CIE Galfor**: Induction furnace and Main press

In Sidenor, the improvement will be mainly focused on the EAF electricity consumption optimization and overall cost reductions related to it, such as electrode consumption, oxygen, natural gas, coal and lime consumption amongst others.

The aim of CIE Galfor at the end of the project is to be able to obtain the LCA and LCCA of two crankshafts (different geometry) produced in the selected line (Glifo). This result will be easily applicable to similar products produced in the same line and will also be the basis to extend the LCA and LCCA to the rest of the production line in CIE Galfor and other Forging Division plants of CIE Automotive group.

The investment approval process at CIE Galfor is based on the calculation of the return on investment from the savings generated compared to the current process. Depending on the investment, the target pay-back varies between 1 and 5 years.

CIE Galfor

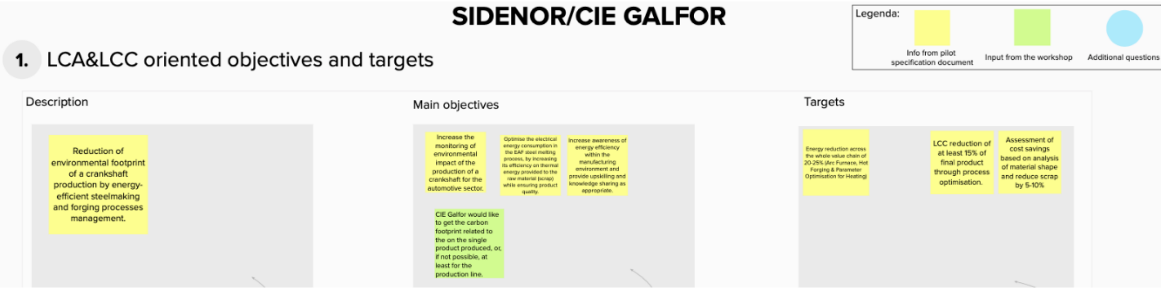
CAPEX: Saw, Induction Furnace, Main & Secondary Press, Robots, cooling system, shot blasting machine, Magnaflux control machine

OPEX: Raw material, forging tooling, induction coils, graphite, electricity, compressed air

Sidenor/CIE Galfor workshop

LCA & LCC workshop

In the first section the description of the pilot as well as the main objectives have been addressed. In Sidenor and CIE Galfor there was the need to better understand the connection between the activities with the aim of identifying the boundaries of the system so the main processes to be considered for the analysis.



SIDENOR/CIE GALFOR

1. LCA&LCC oriented objectives and targets

Legenda: 🟨 Info from pilot specification document 🟩 Input from the workshop ● Additional questions

Description

Reduction of environmental footprint of a crankshaft production by energy-efficient steelmaking and forging processes management.

Main objectives

Increase the monitoring of environmental impact of the production of a crankshaft for the automotive sector.

Optimise the electrical energy consumption in the EAF steel melting process, by increasing its efficiency on thermal energy provided to the raw material (scrap) while ensuring product quality.

Increase awareness of energy efficiency within the manufacturing environment and provide upskilling and knowledge sharing as appropriate.

CIE Galfor would like to get the carbon footprint related to the on the single product produced, or, if not possible, at least for the production line.

Targets

Energy reduction across the whole value chain of 20-25% (Arc Furnace, Hot Forging & Parameter Optimisation for Heating)

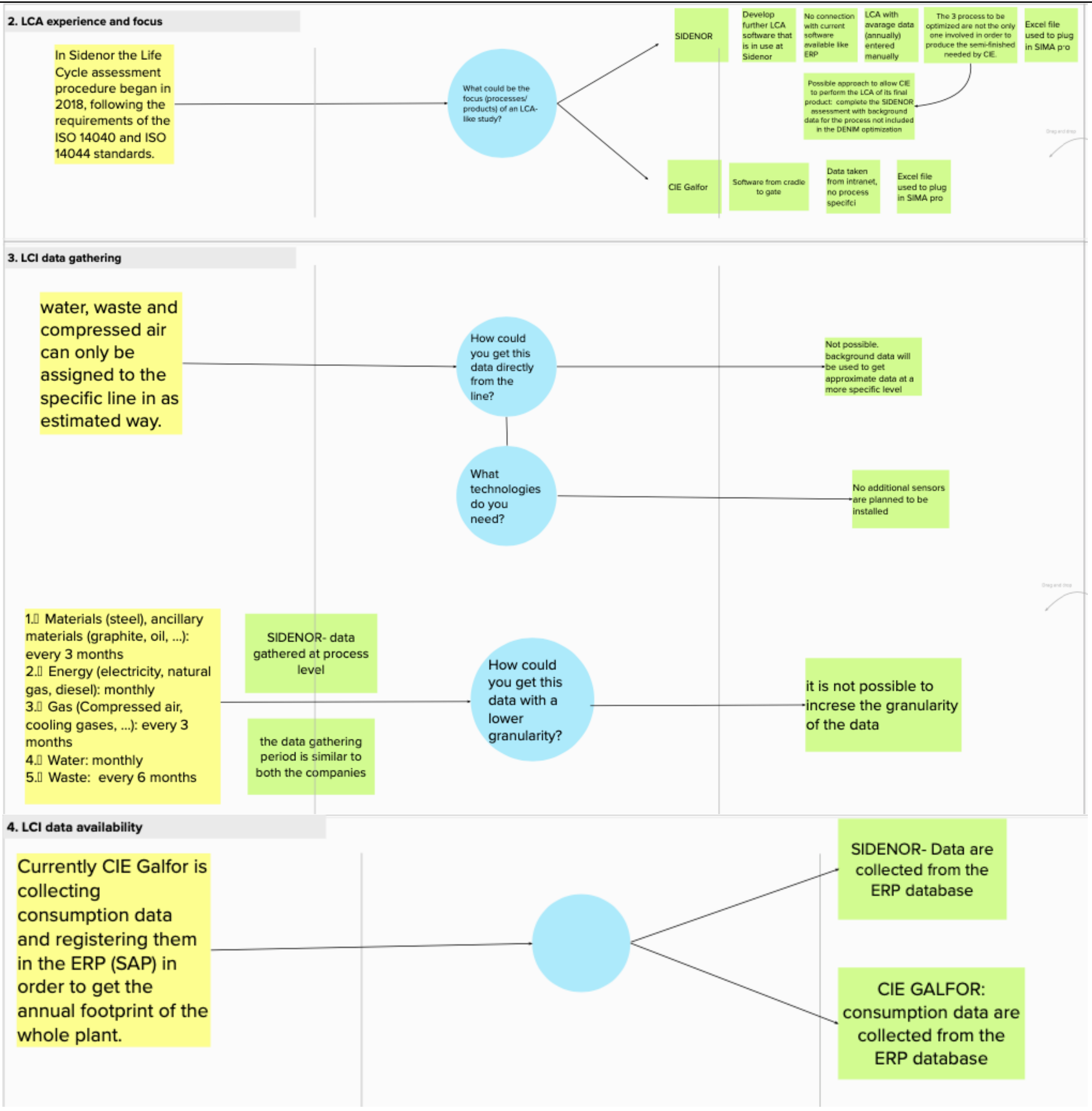
LCC reduction of at least 15% of final product through process optimisation.

Assessment of cost savings based on analysis of material shape and reduce scrap by 5-10%

Figure 12: Sidenor/CIE Galfor Mural board – LCA&LCC oriented objectives and targets

In Sidenor, starting from scrap metals, hot metals and direct reduced iron (DRI) the billets are produced. With respect to DENiM purposes, not all the processes will be included in the analysis, indeed, only EAF, secondary metallurgy and continuous casting will be considered as they are the most relevant from the energy consumption point of view. In CIE Galfor, during the second phase the billets are then heated and forged. The main objective in CIE Galfor is to get the carbon footprint related to the single product, or if it is not possible, for the production line.

In the second section, LCA experience and LCI data gathering have been discussed. According to the answers given in the first excel file (see Appendix VI, Appendix VII, Appendix IV and Appendix V) circulated through the pilots, Sidenor and CIE Galfor already measures a good amount of indicators and lots of methodologies are applied. So, during the workshop the already given information have been deepen with the aim of better understanding the granularity of data and how these can be retrieved.



2. LCA experience and focus

In Sidenor the Life Cycle assessment procedure began in 2018, following the requirements of the ISO 14040 and ISO 14044 standards.

What could be the focus (processes/ products) of an LCA-like study?

SIDENOR

Develop further LCA software that is in use at Sidenor

No connection with current software available like ERP

LCA with avarage data (annually) entered manually

The 3 process to be optimized are not the only one involved in order to produce the semi-finished needed by CIE.

Excel file used to plug in SIMA pro

Possible approach to allow CIE to perform the LCA of its final product: complete the SIDENOR assessment with background data for the process not included in the DENIM optimization

CIE Galfor

Software from cradle to gate

Data taken from intranet, no process specifci

Excel file used to plug in SIMA pro

3. LCI data gathering

water, waste and compressed air can only be assigned to the specific line in as estimated way.

How could you get this data directly from the line?

Not possible. background data will be used to get approximate data at a more specific level

What technologies do you need?

No additional sensors are planned to be installed

1. Materials (steel), ancillary materials (graphite, oil, …): every 3 months
2. Energy (electricity, natural gas, diesel): monthly
3. Gas (Compressed air, cooling gases, …): every 3 months
4. Water: monthly
5. Waste: every 6 months

SIDENOR- data gathered at process level

the data gathering period is similar to both the companies

How could you get this data with a lower granularity?

it is not possible to increse the granularity of the data

4. LCI data availability

Currently CIE Galfor is collecting consumption data and registering them in the ERP (SAP) in order to get the annual footprint of the whole plant.

SIDENOR- Data are collected from the ERP database

CIE GALFOR: consumption data are collected from the ERP database

Figure 13: Sidenor/CIE Galfor Mural board – LCA experience and LCI data gathering

Starting from the input provided in the pilot specification document a set of questions has been defined to deepen the topics. While in Sidenor a LCA procedure began in 2018, following the requirements of the ISO 14040 and ISO 14044 standards, CIE Galfor has no experience in LCA. Regarding LCI data gathering both in Sidenor and CIE Galfor these data are taken at process level and the gathering period is similar. Sidenor has already developed a software used to calculate the environmental impacts of the production plant. LCA is performed annually with average data manually entered and currently there is no connection between the software internally developed and the ERP. To do so, an excel file is plugged in SIMA pro (the LCA software exploited by the company). The three processes highlighted as the most energy-intensive are not the only one involved to produce the semi-finished needed by CIE GALFOR. A possible approach to allow CIE GALFOR to perform LCA on its final product will leverage on background data to complete SIDENOR assessment for the processes not included in the DENiM optimization framework. In Sidenor LCI data will only be available at plant level and it is not possible to increase the granularity of data. Also, no additional sensors are planned to be installed. Functional unit identified for Sidenor processes: 1 ton of steel.

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 958339.

Regarding CIE Galfor, LCA boundaries have been defined (from cradle to gate). The developed software is integrated into the data reporting tool. It uses characterization factors extracted from SimaPro (Ecoinvent database and ReCiPe methodology).

Also, no additional sensors are planned to be installed. Consumption data are collected from the ERP (SAP) database. Energy consumption is measured on the induction furnace, which is the most energy-intensive process, the rest of the data are taken manually at plant level. A further objective could be the development of an environmental label related to the production of one crankshaft. It may be useful to evaluate environmental impacts related to the different alloys. Functional unit identified for CIE Galfor processes: production of one crankshaft.

In the third section the main points that focus LCCA have been discussed.

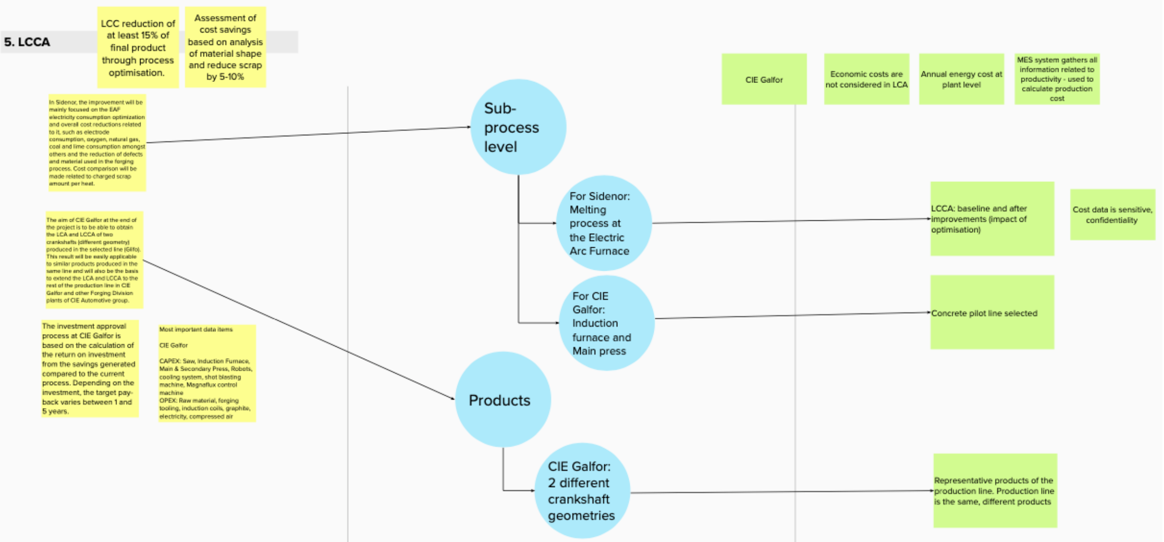


Figure 14: Sidenor/CIE Galfor - Life Cycle Costing

The main outputs of this section are reported in the following bullet points:

- In SIDENOR the melting process at the EAF will be optimized to reduce energy consumption and overall cost.
- In CIE Galfor the focus will be the induction furnace and the main press.
- The main objective of CIE GALFOR is to be able to obtain LCA and LCCA of two crankshafts. The products are representative of the production line.
- Economic costs are considered in LCA.
- Energy costs are calculated annually at plant level.

Production costs are calculated using production data coming from MES.

Next steps

In Sidenor the change of raw materials significantly influences the results of the LCA analysis. This will be thoroughly analysed during the optimization of the EAF process. Indeed, a correct use of the scrap mix and other additions into the furnace will greatly influence in the electrical consumption and yield loss, which will be reflected in the LCA.

4.2.3 Pilot 3: Gorenje Orodjarna – Velenje, Slovenia

Digital Twinning of machining processes to improved planning, design and programming operations for manufacturing of tooling for Appliance Manufacturing

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 958339.

Background

The manufacturing process at Gorenje facilities is very high energy-intensive with a special focus on electrical energy consumption. This process is currently driven by the delivery time, quality and production cost. To ensure the proper production of the products, Gorenje consumes about 150.00 kWh per month of electricity (including 350.000 Nm3/month of compressed air) and almost 100.000 kWh per month of thermal energy. For that reason, Gorenje, within the framework of DENiM will focus efforts on enhancing sustainability and energy efficiency. In this sense, it is expected to increase the digitisation of the machining process (increase by 50%), improve energy consumption (overall annual energy consumption by 10%) and reduce the cost of operation (15% of the final product through process optimisation).

Product/process description

Focus is on manufacturing process of tools like metal injection moulding tool used in automotive industry and making household appliances. No serial production but several different products consisting of hundreds of pieces. Normal order 1-4 tools.

In Figure 15, the key processes at Gorenje Orodjarna are shown:

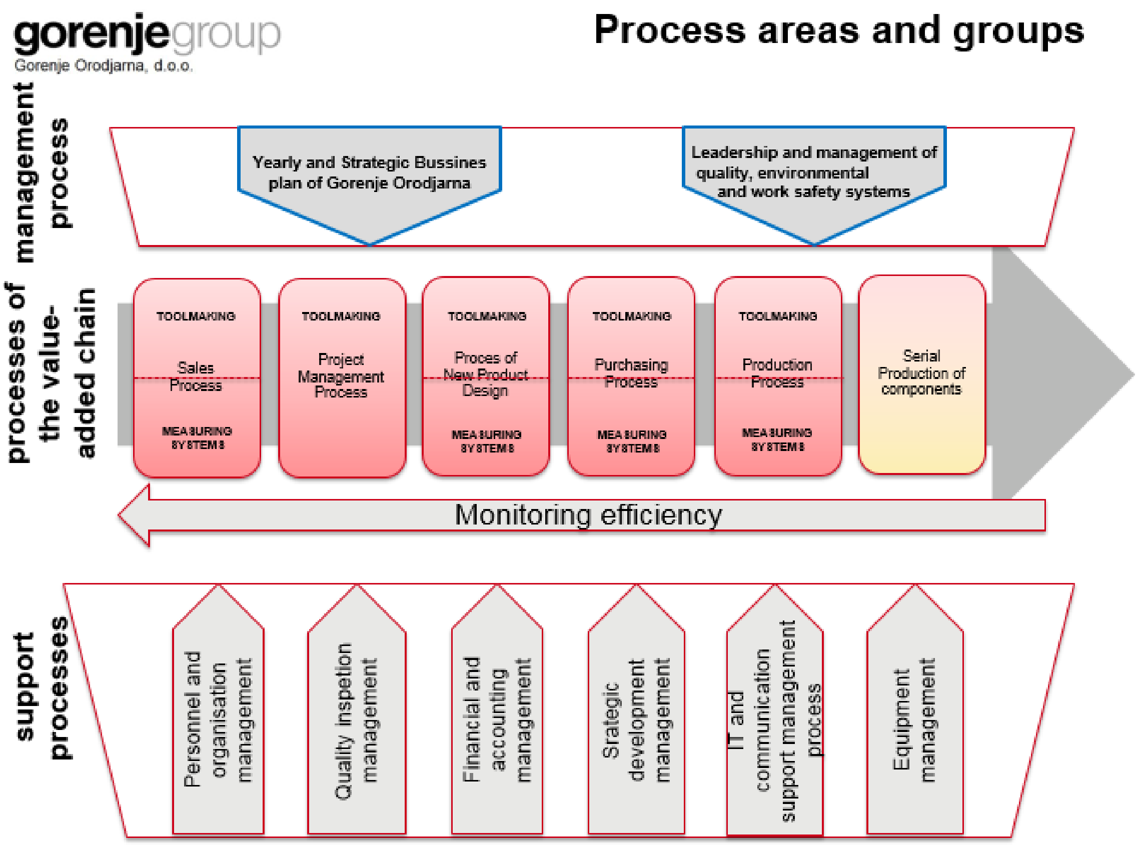


Figure 15: Gorenje's Production processes

Main objectives

The main objectives of the company within the DENiM project are defined as follows:

- Implement machine-based energy and compressed air consumption monitoring
- Find and eliminate the gaps in energy efficiency regarding machines routes
- Integrate new sensors with existing monitoring systems to feed this information into the digital twin
- Analyse the role of each machine

Current challenges

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 958339.

Currently, in Gorenje energy consumption in measured only at facility level. So, additional sensors are required to fill the gap of energy consumption. Lastly, the high variety of production routes increase uncertainty regarding energy impacts.

Expected targets are related to both products and processes. Also, the intention is to be able to define the energy use per machine (now monthly for the whole company, including electricity, thermal energy, water, compressed air).

Current practice

Currently Gorenje is monitoring energy consumption based on historic data and average values. There is a need to perform this analysis with real on-line data in order to improve the accuracy of the impacts.

Main drivers for operation are time to delivery, quality and production costs.

Sensors and monitoring

Gorenje has no sensors installed into machines for collecting energy data, but power meters will be installed to measure parameters such as voltage, current, power…

15 machines that are used for toolmaking in the factory are to be taken into account. There is a need to install sensors to these 15 machines in order to get the energy use data and to plan their usage.

LCA knowledge

The company has never ever experimented any LCA like study and it has not been certified to ISO 50001.

Regarding LCI data, the following data are currently being collected for overall company:

- Materials (steel), ancillary materials (graphite, oil, …): every month
- Energy (electricity): monthly
- Gas (compressed air): monthly
- Water: monthly
- Waste: every month
- Secondary scrap: ever month

These data are currently available in digital format at the overall company level.

LCC knowledge

Life Cycle Cost analysis (LCCA) has never been made in the past. With respect to the DENiM project, LCC will be made on a sub-process, production asset and product level. Based on these it is possible to get LCC picture of whole company.

Investment assessment is implemented during whole year by the group of qualified leaders. Each prepare presentation of their proposals according to needs and profitability. The suggestions are then approved or disapproved by the Company main headquarters.

The most important data items – CAPEX and OPEX data for LCCA

Economic and technical data are available. Firstly, we estimate technical data specification and obtain offers. Then, based on process implementation, we can gather actual data. For example, before buying of a new machine we predict the benefits of investment and then compare actual data with previously predicted. For this example, technical data such as energy sources consumption, efficiency regarding to spent work time and ancillary material consumption are available. Economic data are also available regarding to all technical data such as cost before and after implementation of new machine.

Gorenje workshop

LCA & LCC workshop

In the first section the description of the pilot as well as the main objectives have been addressed. In Gorenje there was the need to clearly understand the most relevant production processes under the energy consumption point of view and the boundaries of system discussing whether the purchased parts have to be considered or not.


GORENJE

1. LCA-oriented objectives and targets

Legenda: 🟨 Info from pilot specification document 🟩 Input from the workshop ● Additional questior

Description

Digital Twinning of machining processes to improved planning, design and programming of operations for manufacturing of tooling for Appliance Manufacturing.

Tooling for Automotive manufacturing

Serial production (stamping) of the components

Main objectives

Identify the machining process's relationship with compressed air to integrate all processes in the analysis of energy savings.

Calculate the corresponding LCA impact contributed by the machining process (n dies during the project, x dies after the project).

Provide information about actual production cost of each piece, which will have a direct impact on Gorenje's commercialisation plan.

Focus: production on Gorenje. The purchased part analysis is not addressed both from the LCA and LCCA point of view.

Focus on compressed air since it is considered the less efficient energy-related process

Targets

90% accuracy of energy and resources used per product and process

5% energy reduction through reducing idling of milling machines

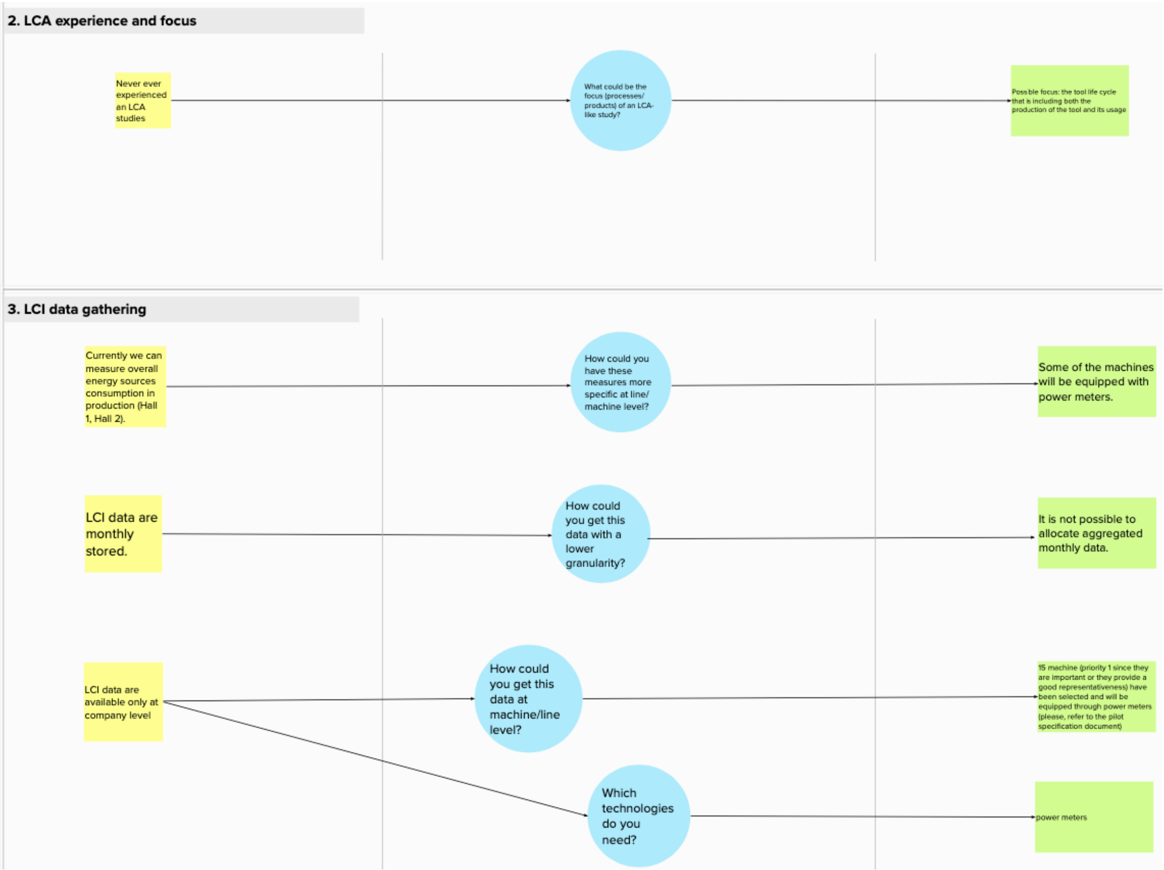
25% reduction of electrical energy via optimal scheduling and planning

Overall annual energy reduction by 10%

Figure 16: Gorenje Mural board- LCA& LCC oriented objectives and targets

In Gorenje there was the need to better understand the product specification to be considered as well as the relevant production processes involved. They explained that the tools produced are used both in the white industry and automotive industry. Only a portion of the components is produced internally (serial stamping production). The rest of the parts are purchased from suppliers. Regarding the main objectives, the pilot will consider only the production in Gorenje for the LCA and LCC analysis. The purchased parts will not be addressed from the LCA point of view. Also, a very low efficient compressed air system has been highlighted, so the need to this into account as well. No comments on the targets have been provided.

In the second section LCA experience and LCI data gathering have been discussed. According to the pilot's inputs, the company already measure the key indicators regarding the main environmental areas, so the discussion focuses on what data are already available, where are they stored and which machines has to be sensorized in order to get other types of data.



2. LCA experience and focus

Never ever experienced an LCA studies

What could be the focus (processes/ products) of an LCA-like study?

Poss ble focus: the tool life cycle that is including both the production of the tool and its usage

3. LCI data gathering

Currently we can measure overall energy sources consumption in production (Hall 1, Hall 2).

How could you have these measures more specific at line/ machine level?

Some of the machines will be equipped with power meters.

LCI data are monthly stored.

How could you get this data with a lower granularity?

It is not possible to allocate aggregated monthly data.

LCI data are available only at company level

How could you get this data at machine/line level?

15 machine (priority 1 since they are important or they provide a good representativeness) have been selected and will be equipped through power meters (please, refer to the pilot specification document)

Which technologies do you need?

power meters

Figure 17: Gorenje Mural board – LCA experience and LCI data gathering

Starting from the input provided in the pilot specification document a set of questions has been defined to deepen the topics. Since Gorenje has never ever experienced an LCA study, the discussion was more focused on the availability and acquisition of LCI data. The focus of the analysis will be the life cycle of the tool, from the production to its usage. Currently, the pilot can measure energy consumption at plant level (hall1, hall2). So, to have a more detailed energy model 15 machines have been selected to be equipped with power meters. Regarding LCI data, these are currently stored monthly and it will not be possible to allocate aggregated monthly data. LCI data are available in digital format in their information system.

In the third section the main points that focus LCCA have been discussed.

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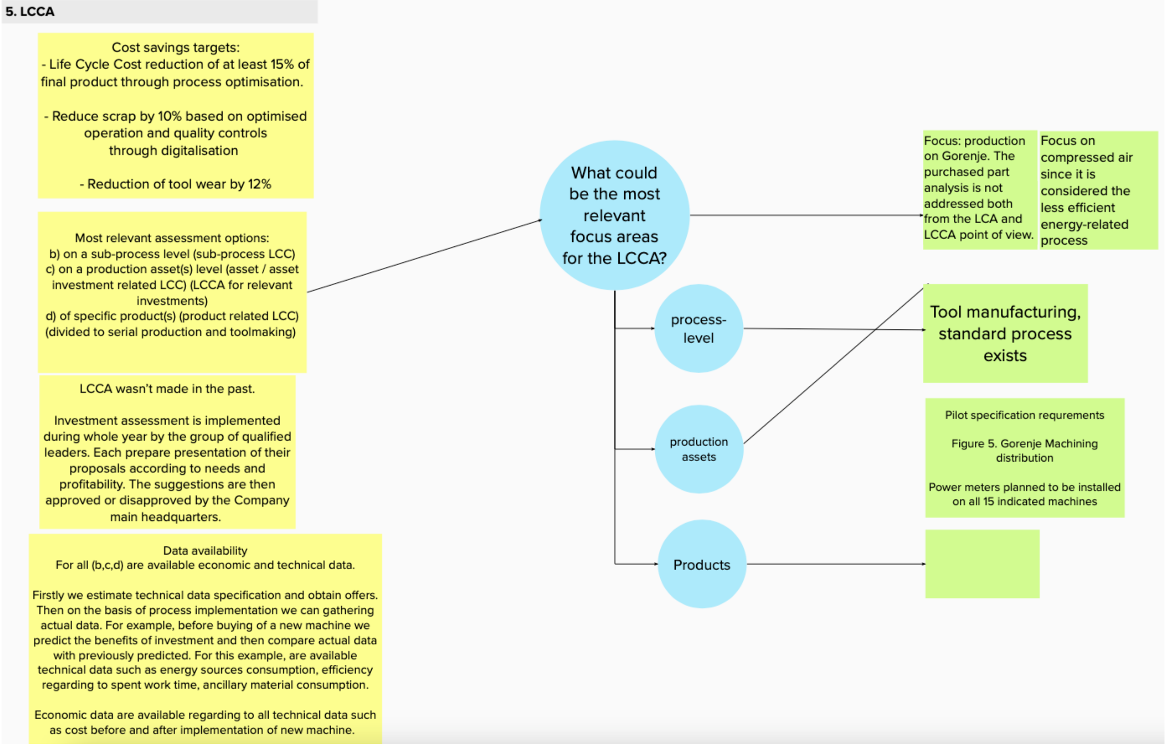

Cost savings targets:
- Life Cycle Cost reduction of at least 15% of final product through process optimisation.

- Reduce scrap by 10% based on optimised operation and quality controls through digitalisation

- Reduction of tool wear by 12%

Most relevant assessment options:
b) on a sub-process level (sub-process LCC)
c) on a production asset(s) level (asset / asset investment related LCC) (LCCA for relevant investments)
d) of specific product(s) (product related LCC) (divided to serial production and toolmaking)

LCCA wasn't made in the past.

Investment assessment is implemented during whole year by the group of qualified leaders. Each prepare presentation of their proposals according to needs and profitability. The suggestions are then approved or disapproved by the Company main headquarters.

Data availability
For all (b,c,d) are available economic and technical data.

Firstly we estimate technical data specification and obtain offers. Then on the basis of process implementation we can gathering actual data. For example, before buying of a new machine we predict the benefits of investment and then compare actual data with previously predicted. For this example, are available technical data such as energy sources consumption, efficiency regarding to spent work time, ancillary material consumption.

Economic data are available regarding to all technical data such as cost before and after implementation of new machine.

Focus: production on Gorenje. The purchased part analysis is not addressed both from the LCA and LCCA point of view.

Focus on compressed air since it is considered the less efficient energy-related process

Tool manufacturing, standard process exists

Pilot specification requrements

Figure 5. Gorenje Machining distribution

Power meters planned to be installed on all 15 indicated machines

Figure 18: Gorenje Mural board – Life Cycle Costing

The main outputs of this section are reported in the following bullet points:

- The focus of the LCCA is the same as the LCA.
- LCCA will be based on the tool manufacturing process
- Production assets have been selected according to the 15 machines identified in the pilot specification requirements.

Next steps
In Gorenje there will be the need to analyse the 15 machines to identify the inventory data and then to establish how to retrieve quantitative information (e.g. add sensors or make some general data allocation…)

4.2.4 Pilot 4: MET, Mantova, Northern Italy

Edge Intelligence for continuous energy optimization in manufacturing of composite components for industrial machines
Background
MET snc, is a highly dynamic SME focusing on the production of mechanical components for the machinery industry. It is located near Mantova, in Northern Italy, a densely industrialised area specialised in instrumental machinery and mechanics, machine tools and packaging-processing machines for the food, beverage and pharmaceutical industry. MET supplies critical components for format change and semi-finished product handling, such as large screws, flanges, bushings, etc., made of diverse composite materials such as polyethylene, polypropylene, nylon and its derivatives.
Product/process description

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Product: Composite component for industrial machines (used for mainly woodworking, composite materials, plastic, glass and stone).

Each component is manufactured after 2-3 machining steps, eventually combined with assembly operations. There is no standard process, and each machine operates as a single cell, although their combination varies continuously depending on the desired shapes, mechanical properties and surface treatments needed.

Figure 19 represents the planimetry of MET's production site.

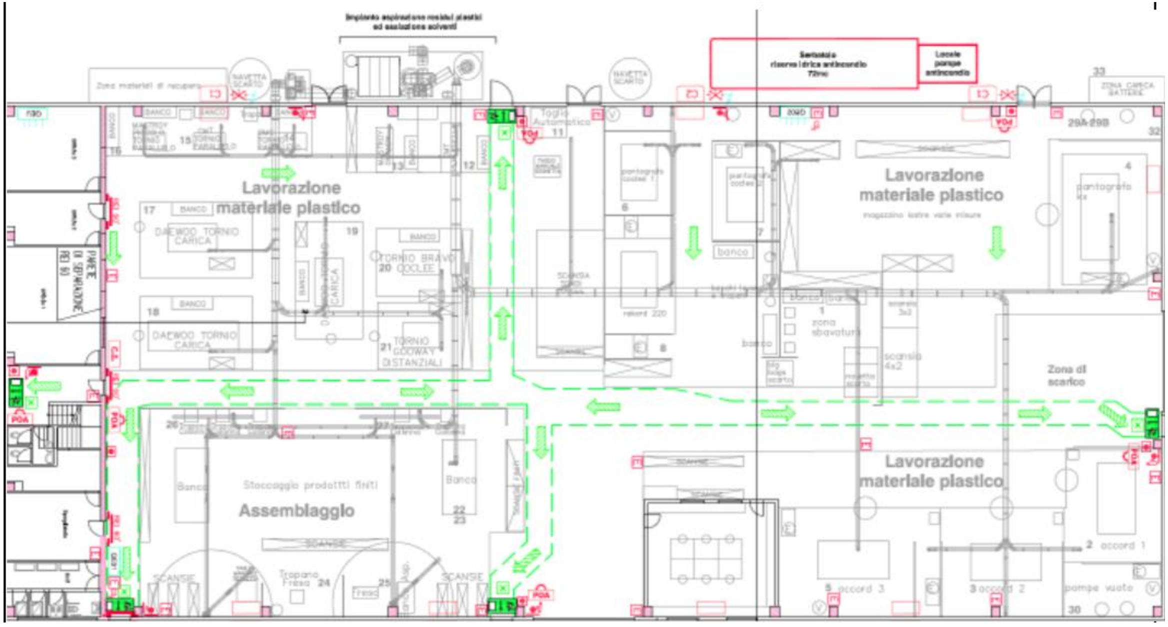

Figure 19: MET's production site planimetry

Main objectives

The main objectives of the company within the DENiM project are defined as follows:

- Acquire visibility on the energy-related elements influencing production cost
- Introduce energy optimisation variable for optimal production set up and schedule
- Increase the monitoring of environmental impact of products
- Provide capabilities to visual asset energy use in "real-time"

Current challenges

Currently MET has limited monitoring of asset data from an energy perspective and data collection is manual and very labour intensive. Also, no visibility of energy performance at process level.

There is no production control system (like MES) or data collection, thus in practise there is no data about the processes. SCM has an IoT platform MAESTRO Connect, and the intention is to utilise it in the product by implementing "smart energy" tool.

Current practice

Currently main drivers for operation are time to delivery (key in this business), quality and mainly production costs. Nonetheless, sustainability and energy efficiency are becoming more important, not only for their impact in production costs but also for the increased interest of the customers on ensuring a low-carbon footprint production. The company has different sustainability indicators such as overall energy consumption, water use and compressed air.

There are 2-3 machine stages on average to produce one product. For each order, the machines have new settings but the operation is lean.

Sensors and monitoring

The machines already have many sensors for controlling the primary activities of the machine air pressure, vacuum for fixing the material, spindle rotations aligned with centralized suction.

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Sensors can be installed upstream to measure energy absorbed by each machine, compressed air consumption and vacuum flow rate.
SCM: Some machines have been chosen for the project (3). Sensors for these are being installed just now to measure energy use.

LCA knowledge

MET has no experience on LCA practices, while the IoT Maestro platform could gather some relevant data (based mainly on the energy consumption) that could be used to calculate the specific carbon footprint of each manufacturing operation. It is expected that MET's clients will require LCA data of the products in the future. Machine tool simulation models could be improved with energy consumption data and input and output flows. No LCI data is available at current state

LCC knowledge

LCCA tools are not in use. The energy consumption of the process is not monitored => energy cost cannot be predicted although it should be better predicted according to the orders.

MET workshop

LCA & LCC workshop

In the first section the description of the pilot as well as the main objectives have been addressed. In MET there was the need to better understand the product and related production line so to identify the relevant machines to be considered in the analysis.

Figure 20: MET Mural board – LCA&LCC oriented objectives and targets

MET explained that the pieces produced are related to the bottling and labelling industry. Each product is custom and made of several materials and follows a production path depending on the order. For addressing LCA and LCCA three machines have been selected to be representative of the shopfloor so, these can be used as a replication of the machines in the remaining part of the plant. Two of them are three-axis and one is five x-axes. These machines are used for drilling and milling. In general, the main production processes include are: laser cutting, CNC machine, waterjet cutting, surface polishing and turning. Only the production in MET will be considered for the LCA and LCC analysis.

In the second section LCA experience and LCI data gathering have been discussed. According to the answer given in the first excel sheet (see Appendix X and Appendix XI), the company does not have any experience with environmental studies. Also, MET does not monitor any kind of indicators, neither for environmental reporting nor for process optimization. This phase has been helpful to start discussing a sensorization plan in order to get the data needed for the LCA and LCCA.

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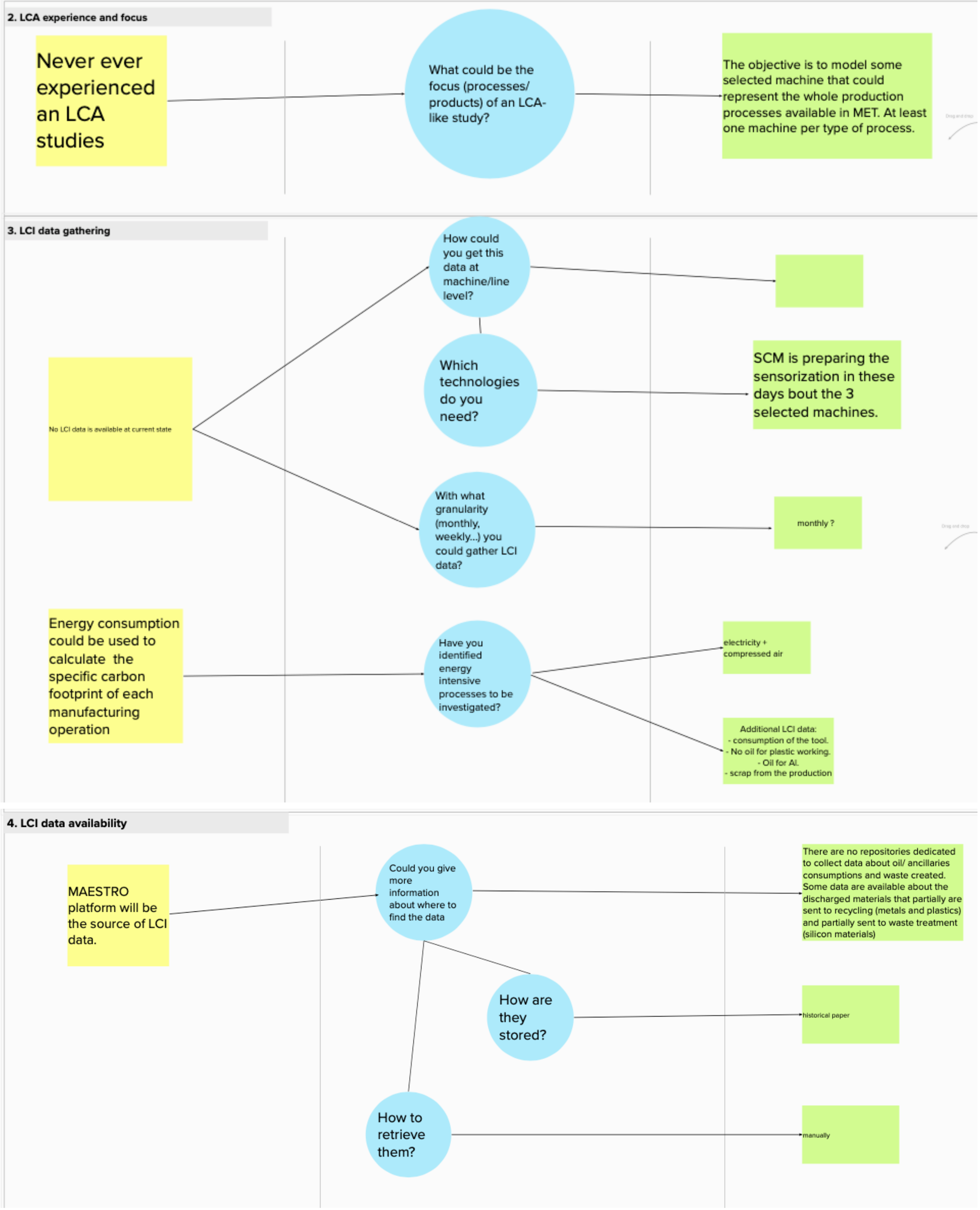

Figure 21: MET - LCA focus and LCI data gathering

MET has never ever experienced any LCA-like studies. The objective is to model some selected machines that could represent the whole production process available in MET. At least one machine per type of process. Regarding LCI data gathering, currently the machines do not collect any data so LCI data are not directly available. Energy meters and sensors will be installed on the three selected machines to gather data to optimise energy consumption and compressed air usage. Only these machines have been selected because they are the newest and it is easier to install the sensors. The sensorizing activity is divided into two steps. The first aims at obtaining a detailed view of energy consumption. The second aims at calculating the carbon footprint for each task going beyond

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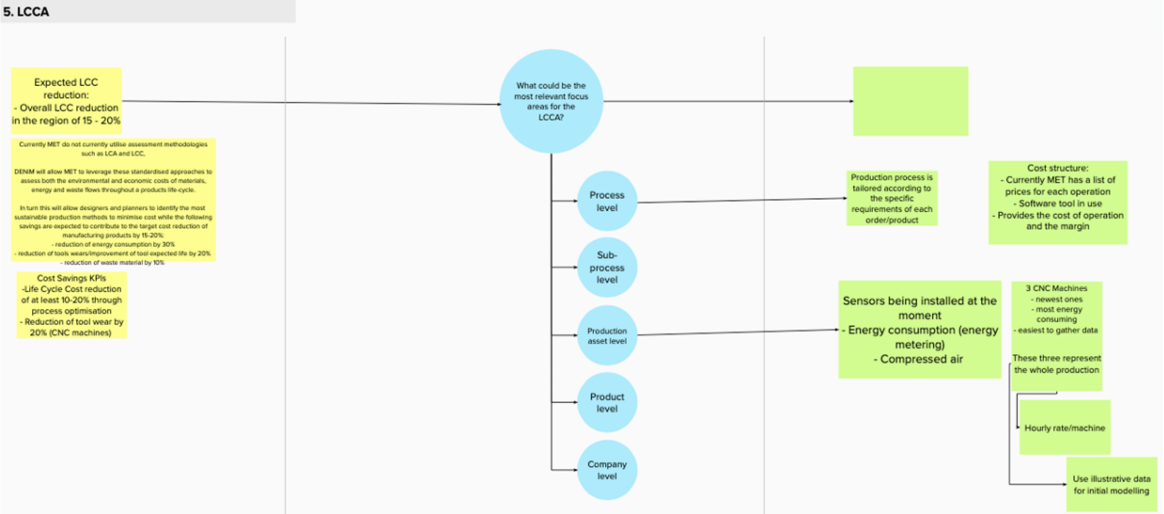
optimizing the production processes in terms of energy consumption. Additional LCI data such as consumption of the tools, oil usage, and scrap from production will be collected. There are no repositories dedicated to collect data about ancillaries material consumption and waste created. Some data are available about the discharged material that is partially sent to recycling (metals and plastics) and partially sent to waste treatments (silicon materials). These data will not be gathered directly on the machines.

In the third section the main points that focus LCCA have been discussed.



Currently MET do not currently utilise assessment methodologies such as LCA and LCC.

DENIM will allow MET to leverage these standardised approaches to assess both the environmental and economic costs of materials, energy and waste flows throughout a products life-cycle.

In turn this will allow designers and planners to identify the most sustainable production methods to minimise cost while the following savings are expected to contribute to the target cost reduction of manufacturing products by 15-20%:
- reduction of energy consumption by 30%
- reduction of tools wears/improvement of tool expected life by 20%
- reduction of waste material by 10%

Figure 22: MET Mural board – Life Cycle Costing

The main outputs of this section are reported in the following bullet points:

- The focus of the LCCA is the same as the LCA. Currently MET has a list of prices for each operation.
- Currently MET has a list of prices for each operation.
- The software provides the cost for singular operation and the margin.
- MET has a customer portfolio of about 20, with an annual production of about 20000 pieces.

Next steps

In MET there will be the need identify representative products (e.g. product families or "standard products") to be related to typical routings. Also, all the machines to be included in the evaluation as well as the new sensors have to be defined.

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5 LCA & LCCA framework design

The objective of the work reported in this section was to design the framework that will support the different levels of the DENiM platform in the acquisition, elaboration and presentation of the information and data required to optimise the performances of the company under the sustainability perspectives. To this end the activity, whose main focus is the design of the assessment methodology and the indicators to analyse production performances and costs under the sustainability perspective, will took into account the principal elements where the indicators are framed in.

The quantification of emissions and resources consumed as well as the related environmental and economic impacts can be enabled by the scientific and standardised approach of LCA and LCCA. The literature review carried out in the previous chapters highlighted how the two methodologies are the most comprehensive and broad, currently available in literature, reason why these have been selected as main guidelines to fulfil the different needs of assessment that can be identified within the industrial scenarios that the project addresses.

The developed framework is a pivotal element in the DENiM platform as it has a central role in supporting the achievement of few of its objectives. As depicted in the following picture, it is meant to take into consideration the input deriving from the different nature of the pilots, either in terms of assessment domain and granularity, and be connected with the data acquisition, calculation and optimisation technologies supporting the real time assessment and exploitation of the impact data generated.

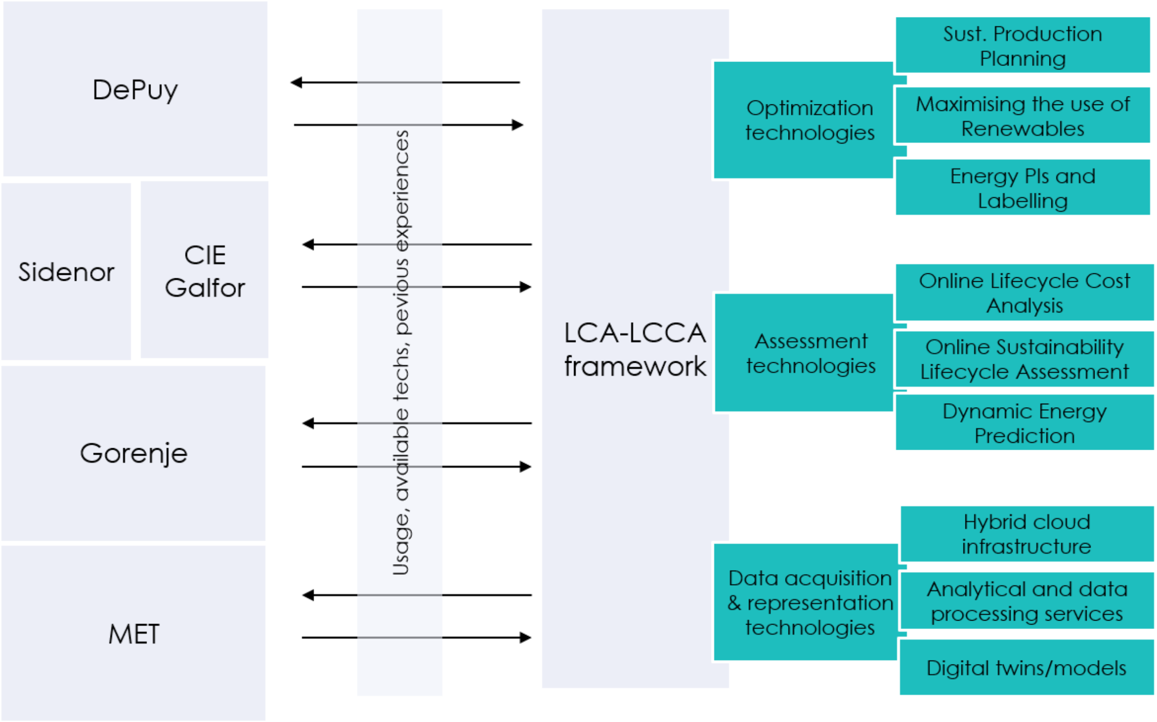

Figure 23: LCA - LCCA DENiM framework

The realization of a robust assessment methodology requires current and accurate data necessary to create a knowledge base to support the calculation of the lifecycle impacts to be assessed. The developed framework will be therefore seamlessly integrated in the online assessment technologies that will exploit the DENiM data acquisition layer that will enable the collection of real-time data (e.g. energy and carbon input/outputs), this making sustainability assessment much more precise and automated compared with today’s conventional methods.

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5.1 Introduction to the DENiM indicators' framework

Similarly to the structure identified in the state of the art analysis presented in section 3, the DENiM indicators framework is organized in three main areas: environment and cost & profitability. The environmental indicators offer a two level vision, the inventory and the impact one. According to the inventory indicators analysed in section 3.3.1, these have been split into 5 different categories (waste, emissions, material, water, energy) as stated in GRI 300. This classification allows for a broader view of the company's performance by identifying any hotspots to be monitored or further investigated for each area. For each group of indicators, at least 1 major KPI has been selected and then broken down into its structure. This allows to identify a list of sub-indicators that permits having a complete overview of all the parameters contributing to the selected KPI. Also, it is suggested to express each major indicator as an intensity ratio after the identification of a proper normalisation factor (nf), so to set the basis for a significant comparative analysis. Regarding impact indicators, according to the Product Environmental Footprint and Organisation Environmental Footprint (OEF) 16 impact indicators have been identified (Table 6). Then, the Environmental Product Declaration (EPD) has been introduced (Table 7) allowing for a reduction of the number of impact KPI from 16 to 7. In this section it is important to highlight that all the indicators will be calculated using direct data, meaning that only the resource use and emissions involved in the production will be considered in the calculation. This approach has been adopted in order to avoid DENiM use cases to collect primary LCI data along their entire supply chain, but assure to obtain an indication at inventory level that is related directly to the activities carried out. This provides a more direct vision on the possible actions to be implemented for the reduction of both use of resources and emissions. The indirect effects perspective is then guarantee by the impact level that is evaluated in a life cycle perspective.

Regarding economic indicators different types are used to measure companies' financial performance. In DENiM, the focus is on cost accounting (i.e. not on financial accounting) and thus the most important indicators are related to costs and profitability. Where the first ones are OPEX (the most relevant within DENiM) and CAPEX, while the seconds aim to produce comparison scenario before and after DENiM deployment. As for the inventory indicators a similar structure has been reproduced where sub-indicators are needed to calculate lead KPI(s).

Considering that the set of indicators allows for a snapshot of the company, it is therefore important to underline the value of dynamic variation indicators to assess the performances of the company comparing different periods. Thus, each major KPI will be supported by a variation index showing the differences between time spans.

Even though social indicators have been reported in section 3.3.1, they will not be used as they are not connected with the DENiM framework.

5.2 Environmental indicators

5.2.1 Inventory indicators

As reported in section 3.3.1 all the inventory indicators taken from literature have been assigned to a specific environmental aspect according to GRI 300: Environmental Disclosure. The 5 areas that gives a complete overview of the environmental performances of a company are waste, emissions, materials, water and energy. Then, at least one major KPI (see highlighted indicators from Table 9 to Table 16) has been defined which has been broken down into its structure identifying a list of sub-indicators. For each area, the general description, the graphic structure of KPIs and the table containing mathematical formulas of each KPI and sub-indicators is provided below.

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Direct waste

Waste can be generated in the organization's own activities, for example, during the production of its products and delivery of services. Waste can have significant negative impacts on the environment and human health when inadequately managed. These impacts often extend beyond locations where waste is generated and discarded. The resources and materials contained in waste that is incinerated or landfilled are lost to future use, which accelerates their depletion (*Gri-306-Waste-2020*, n.d.). The main KPIs and their data structure are reported in Figure 24.

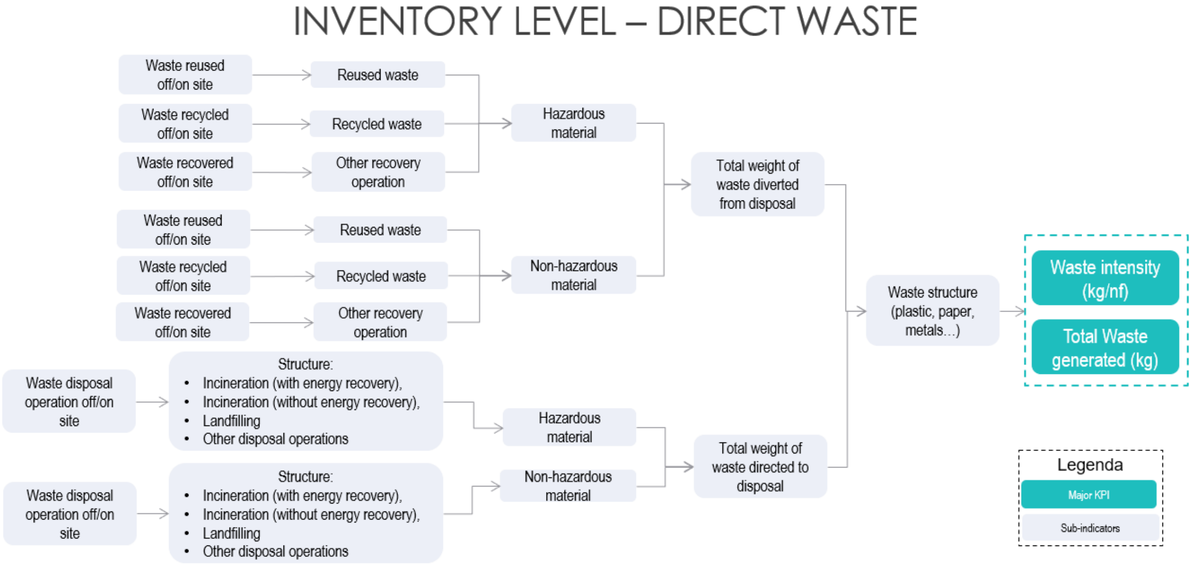

Figure 24: Direct waste - data structure

The main KPI selected to be visualized are *Total waste generated* and *waste intensity*. The latter is used for a better understanding of the performance since the normalization factor allows to track measures usually depending on production volume. Then, in order to have a better vision of the topic, it is suggested to define the waste structure according to the different types of waste (plastic, paper, metal).Table 9, Table 10 and Table 11 provide the formulas of the previously presented indicators.

Table 9: Direct waste indicators - high level indicators

Indicator	Formula	Unit
Total waste generated	**-**	**kg**
Waste intensity	$\boldsymbol{\frac{Total\ waste\ generated\ (kg)}{normalisation\ factor}}$	**kg/nf**
% of plastic/paper/metals…	$\frac{total\ plastic/paper/metals\ \ldots\ (kg)}{total\ waste\ generated\ (kg)} * 100$	%

After the definition of waste structure two branches have been identified. The first related to waste diverted from disposal concerns the total volume of waste sent to recovery operations. Then, this is divided into hazardous and non-hazardous waste, defining the structure of recovery operations (reused, recycled, other) and lastly the amount of waste which is recovered off/on site.

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Table 10: Direct waste indicators - waste diverted from disposal

Indicator	Formula	Unit
% of waste diverted from disposal	$\frac{total\ waste\ diverted\ from\ disposal\ (kg)}{total\ waste\ generated\ (kg)} * 100$	%
% of hazardous material diverted from disposal	$\frac{total\ hazardous\ waste\ diverted\ from\ disposal\ (kg)}{total\ waste\ diverted\ from\ disposal\ (kg)} * 100$	%
% of non-hazardous material diverted from disposal	$\frac{total\ non - hazardous\ waste\ diverted\ from\ disposal\ (kg)}{total\ waste\ diverted\ from\ disposal\ (kg)} * 100$	%
% of hazardous waste reused	$\frac{total\ hazardous\ waste\ \text{reused}\ (kg)}{total\ hazardous\ waste\ diverted\ from\ disposal\ (kg)} * 100$	%
% of hazardous waste recycled	$\frac{total\ hazardous\ waste\ \text{recycled}\ (kg)}{total\ hazardous\ waste\ diverted\ from\ disposal\ (kg)} * 100$	%
% of hazardous waste sent to other recovery operations	$\frac{total\ waste\ sent\ to\ other\ recovery\ operations\ (kg)}{total\ hazardous\ waste\ diverted\ from\ disposal\ (kg)} * 100$	%
% of non-hazardous waste reused	$\frac{total\ non - hazardous\ waste\ \text{reused}\ (kg)}{total\ non - hazardous\ waste\ diverted\ from\ disposal\ (kg)} * 100$	%
% of non-hazardous waste recycled	$\frac{total\ non - hazardous\ waste\ \text{recycled}\ (kg)}{total\ non - hazardous\ waste\ diverted\ from\ disposal\ (kg)} * 100$	%
% of non-hazardous waste sent to other recovery operations	$\frac{total\ non - hazardous\ waste\ sent\ to\ other\ recovery\ operations\ (kg)}{total\ non - hazardous\ waste\ diverted\ from\ disposal\ (kg)} * 100$	%
% of waste reused on site	$\frac{total\ waste\ reused\ on\ site\ (kg)}{total\ waste\ \text{reused}\ (kg)} * 100$	%
% of waste recycled on site	$\frac{total\ waste\ recycled\ on\ site\ (kg)}{total\ waste\ \text{recycled}\ (kg)} * 100$	%
% of waste recovered on site	$\frac{total\ waste\ recovered\ on\ site\ (kg)}{total\ waste\ \text{recovered}\ (kg)} * 100$	%

The second branch is related to waste directed to disposal and after a first classification of hazardous and non-hazardous waste, these are broken down into their disposal operations (incinerator, landfilling, other). Lastly, waste disposal operations off/on site are measured.

Table 11: Direct waste indicators - waste directed to disposal

Indicator	Formula	Unit
% of waste directed to disposal	$\frac{total\ waste\ directed\ to\ disposal\ (kg)}{total\ waste\ generated\ (kg)} * 100$	%

% of hazardous material directed to disposal	$\frac{total\ hazardous\ waste\ directed\ to\ disposal\ (kg)}{total\ waste\ directed\ to\ disposal\ (kg)} * 100$	%
% of non-hazardous material directed to disposal	$\frac{total\ non - hazardous\ waste\ directed\ to\ disposal\ (kg)}{total\ waste\ directed\ to\ disposal\ (kg)} * 100$	%
% of hazardous waste directed to incinerator	$\frac{total\ hazardous\ waste\ directed\ to\ \text{incinerator}\ (kg)}{total\ hazardous\ waste\ directed\ to\ disposal\ (kg)} * 100$	%
% of hazardous waste directed to landfilling	$\frac{total\ hazardous\ waste\ directed\ to\ \text{landfilling}\ (kg)}{total\ hazardous\ waste\ directed\ to\ disposal\ (kg)} * 100$	%
% of hazardous waste directed to other disposal operations	$\frac{total\ hazardous\ waste\ directed\ to\ \text{other disposal operations}\ (kg)}{total\ hazardous\ waste\ directed\ to\ disposal\ (kg)} * 100$	%
% of non-hazardous waste directed to incinerator	$\frac{total\ non - hazardous\ waste\ directed\ to\ \text{incinerator}\ (kg)}{total\ non - \ hazardous\ waste\ directed\ to\ disposal\ (kg)} * 100$	%
% of waste directed to landfilling	$\frac{total\ non - hazardous\ waste\ directed\ to\ \text{landfilling}\ (kg)}{total\ non - hazardous\ waste\ directed\ to\ disposal\ (kg)} * 100$	%
% of waste directed to other disposal operation	$\frac{total\ non - hazardous\ waste\ directed\ to\ \text{other disposal operations}\ (kg)}{total\ non - hazardous\ waste\ directed\ to\ disposal\ (kg)} * 100$	%
% of hazardous waste disposed on site	$\frac{total\ hazardous\ waste\ disposed\ on\ site\ (kg)}{total\ hazardous\ waste\ directed\ to\ disposal\ (kg)} * 100$	%
% of non-hazardous waste disposed on site	$\frac{total\ non - hazardous\ waste\ disposed\ on\ site\ (kg)}{total\ non - hazardous\ waste\ directed\ to\ disposal\ (kg)} * 100$	%

Direct emissions

Emissions into air are the discharge of substances from a source into the atmosphere. The main types of emissions include: greenhouse gases (GHG), ozone-depleting substances (ODS) and nitrogen oxides (NO_x) and sulphur oxides (SO_x), among other significant air emissions. These pollutants have adverse effects on climate, ecosystem, air, quality, habitats, agriculture and human health. Deterioration of air quality and acidification have led to local and international regulations to control emissions of these pollutants. Other significant air emissions include, for example, persistent organic pollutants or particulate matter, as well as air emissions that are regulated under international conventions and/or national laws or regulations, including those listed on an organization's environmental permits (*Gri-305-Emissions-2016*, n.d.-b). The main KPIs and their data structure are reported in Figure 25, while the indicators with the formulas are reported inTable 12Table 12.

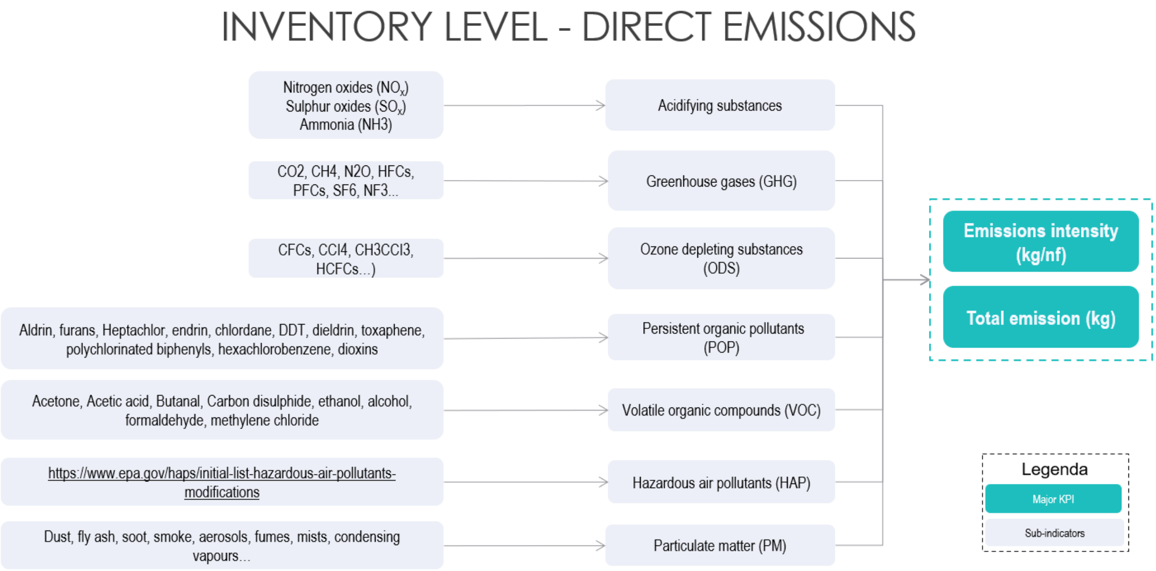

Figure 25: Direct emissions - data structure

The main KPIs selected to be visualized are *total emission* and *emission intensity*. Then, with the aim of better understanding how the topic is treated by the company the emissions' structure has been defined according to GRI 305 classification.

Table 12: Direct emissions- Indicators

Category	Indicator	Formula	Unit
Direct emissions	**Total emissions**	**-**	**kg**
	Emissions intensity	$\frac{\boldsymbol{Total\ emissions\ (kg)}}{\boldsymbol{normalisation\ factor}}$	**kg/nf**
	% of acidifying substances	$\frac{Total\ acidifying\ substances\ (NO_x, SO_x, NH_3\ \ldots)(kg)}{total\ emissions\ (kg)} * 100$	%
	% of greenhouse gases (GHG)	$\frac{Total\ GHG\ (CO_2, CH_4, N_2O\ \ldots)\ (kg)}{total\ emissions\ (kg)} * 100$	%
	% of ozone depleting substances (ODS)	$\frac{Total\ ODS\ (CFCs\ \ldots)\ (kg)}{total\ emissions\ (kg)} * 100$	%
	% of persistent organic pollutants (POP)	$\frac{Total\ POP\ (aldrin, furans\ \ldots)\ (kg)}{total\ emissions\ (kg)} * 100$	%
	% of volatile organic compounds (VOC)	$\frac{Total\ VOC\ (acetone, ethanol\ \ldots)\ (kg)}{total\ emissions\ (kg)} * 100$	%
	% of hazardous air pollutants (HAP)	$\frac{Total\ HAP\ (acrolein, chlorine\ \ldots)\ (kg)}{total\ emissions\ (kg)} * 100$	%
	% of particulate matter (PM)	$\frac{Total\ PM\ (dust, fly\ ash\ \ldots)\ (kg)}{total\ emissions\ (kg)} * 100$	%

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Direct material

The inputs used to manufacture and package an organization's products and services can be non-renewable materials, such as minerals, metals, oil, gas, or coal; or renewable materials, such as wood or water. Both can be composed of virgin or recycled input materials. The type and amount of materials the organization uses can indicate its dependence on natural resources, and the impacts it has on their availability. The main KPIs and their data structure are reported in Figure 26, while the indicators with the formulas are reported in Table 13.

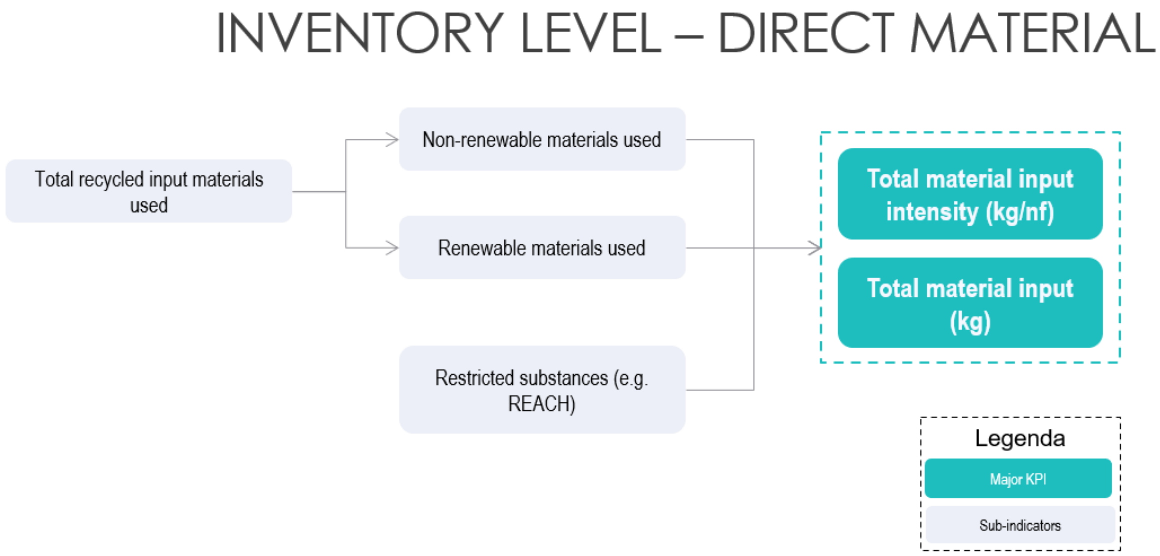

Figure 26: Direct material - data structure

The main KPIs selected to be visualized are *total material input* and *total material input intensity*. Then, a split into renewable and non-renewable materials is fundamental so to have a better view of the distribution of input material within the company. Recycled materials are also considered so to contribute to the assessment of the company on this topic. Lastly, restricted substances are also considered according to REACH regulation. Table 1313 provide the list of indicators according to the structure presented.

Table 13: Direct material - Indicators

Category	Indicator	Formula	Unit
Direct material	**Total material input**	-	**kg**
	Total material input intensity	$\frac{\boldsymbol{Total\ material\ input\ (kg)}}{\boldsymbol{normalisation\ factor}}$	**kg/nf**
	% renewable materials used	$\frac{Total\ renewable\ materials\ used\ (kg)}{total\ material\ input\ (kg)} * 100$	%
	% of non-renewable materials used	$\frac{Total\ non-renewable\ materials\ used\ (kg)}{total\ material\ input\ (kg)} * 100$	%
	% of total recycled input materials	$\frac{Total\ recycled\ materials\ used\ (kg)}{total\ material\ input\ (kg)} * 100$	%

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	% of restricted substances (e.g. REACH)	$\frac{Total\ restricted\ substances\ by\ regulations\ (kg)}{total\ material\ input\ (kg)} * 100$	%

Direct water

The amount of water withdrawn and consumed by an organization and the quality of its discharges, can impact the functioning of the ecosystem in numerous ways. Direct impacts on a catchment can have wider impacts on the quality of life in an area, including social and economic consequences for local communities and indigenous peoples. Through a comprehensive understanding of its water use, an organization can assess the impacts it has on water resources that benefit the ecosystem, other water users, and the organization itself. The main KPIs and their data structure are reported in Figure 27, while the indicators with the formulas are reported in Table 14and Table 15.

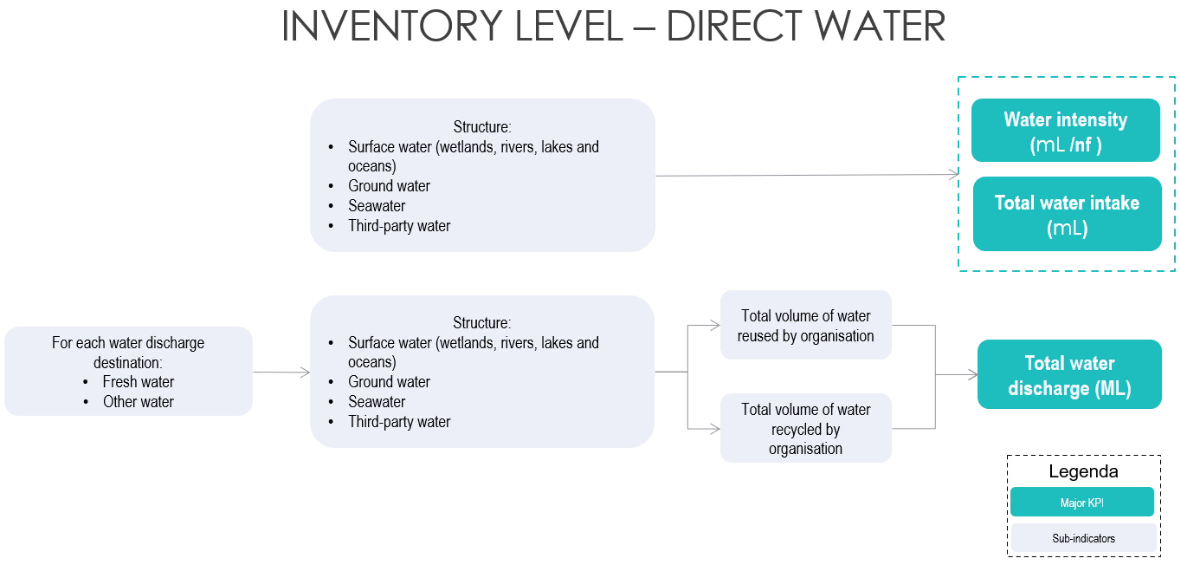

Figure 27: Direct water - data structure

The main KPIs selected to be visualized are total water intake, water intensity and total water discharge. The first two refers to input water and a classification based on the source (surface water, ground water…) is needed.

Table 14 Direct water indicators - water intake

Indicator	Formula	Unit
Total water intake	**-**	**ML**
Water intensity	$\frac{\boldsymbol{Total\ water\ intake\ (ML)}}{\boldsymbol{normalisation\ factor}}$	**ML/nf**
% of water withdrawn from the following sources: (i) surface water, (ii) ground (iii) water, (iv)seawater, third-party water	$\frac{Total\ water\ intake\ from\ a\ source\ i\ (ML)}{total\ water\ intake\ (ML)} * 100$	%

The third indicator refers to output water, considering the distribution of final destination as well as the quality of water, where fresh water contains less than 1000 mg/L of total dissolved solids.

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Table 15: Direct water indicators - water discharge

Indicator	Formula	Unit
Total water discharge	**-**	**ML**
% of water reused/recycled by the organisation	$\frac{Total\ water\ reused/recycled\ (ML)}{total\ water\ discharge\ (ML)} * 100$	
% of water discharge to the following sources: (i) surface water, (ii) ground (iii) water, (iv)seawater, third-party water	$\frac{Total\ water\ discharge\ to\ a\ source\ i\ (ML)}{total\ water\ discharge\ (ML)} * 100$	%
% of fresh water (≤ 1,000 mg/L Total Dissolved Solids) discharge for each destination	$\frac{Total\ fresh\ water\ discharge\ (ML)}{total\ water\ discharge\ (kg)} * 100$	%

Direct energy

An organization can consume energy in various forms, such as fuel, electricity, heating, cooling or steam. Energy can be self-generated or purchased from external sources and it can come from renewable sources (such as wind, hydro or solar) or from non-renewable sources (such as coal, petroleum or natural gas). Using energy more efficiently and opting for renewable energy sources is essential for combating climate change and for lowering an organization's overall environmental footprint. The main KPIs and their data structure are reported in Figure 28.

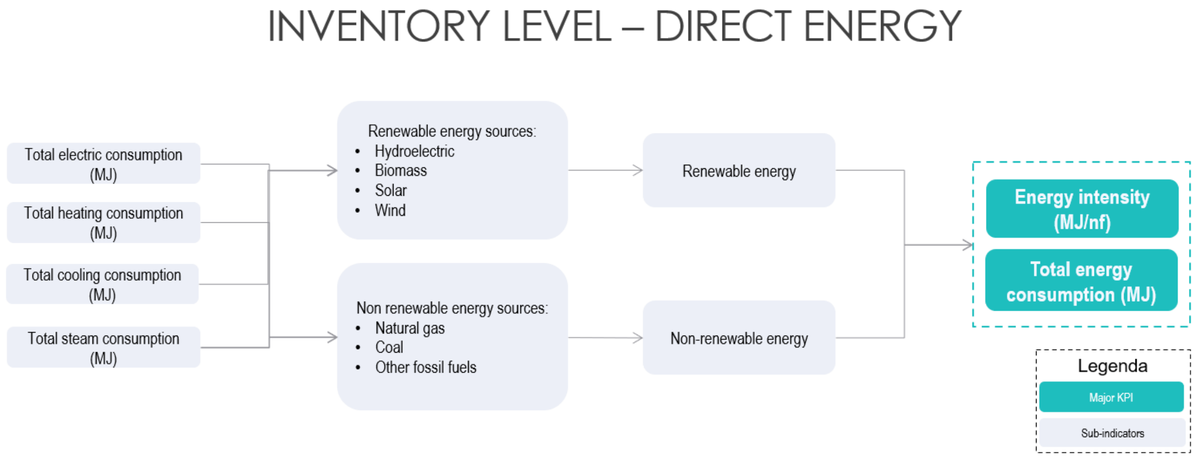

Figure 28: Direct energy - data structure

The main KPIs selected to be visualized are *total energy consumption* and *energy intensity*. Then, a first classification between renewable and non-renewable is reported to better understand dependence of non-renewable energy sources of the company. Lastly it is suggested to report total consumptions divided into the different types of energy (electric, heating…). Table 16 provide the list of indicators according to the data structure identified.

Table 16: Direct energy - Indicators

Category	Indicator	Formula	Unit
Direct energy	**Total energy consumption**	**-**	**MJ**
	Energy intensity	$\frac{\boldsymbol{Total\ energy\ consumption\ (MJ)}}{\boldsymbol{normalisation\ factor}}$	**MJ/nf**
	% of renewable energy consumption	$\frac{Total\ renewable\ energy\ consumption\ (MJ)}{total\ energy\ consumption\ (MJ)} * 100$	
	% of renewable energy consumption generated by the following sources: (i) hydroelectric, (ii) biomass (iii) solar, (iv) wind	$\frac{Total\ renewable\ energy\ generated\ by\ a\ source\ i\ (MJ)}{total\ water\ discharge\ (ML)} * 100$	%
	% of non-renewable energy consumption	$\frac{Total\ non - renewable\ energy\ consumption\ (MJ)}{total\ energy\ consumption\ (MJ)} * 100$	%
	% of renewable energy consumption generated by the following sources: (i) natural gas, (ii) coal, (iii) other fossil fuels	$\frac{Total\ non - renewable\ energy\ generated\ by\ a\ source\ i\ (MJ)}{total\ water\ discharge\ (ML)} * 100$	%
	Total electric consumption	-	MJ
	Total heating consumption	-	MJ
	Total cooling consumption	-	MJ
	Total steam consumption	-	MJ

5.2.2 Impact indicators

PEF and OEF provide a list of 16 impact indicators that help assess the environmental performance of products/services/organisation across their life-cycle, converting inventory into impacts on the environment through characterization models. OEF and PEF make it possible to quantify environmental performance from a life cycle point of view. Whereas the method for calculating PEF is specific to individual products or services, the method for calculating OEF applies to the activities of

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organisations as a whole, i.e. to all activities associated with the products and/or services supplied by an organisation in terms of its procurement chain (from extraction of raw materials, to use and options for the final disposal of waste). These methodologies provide a measurement of the environmental performance of your organisation and/or products and services so that you can identify potential improvement actions. Also, as mentioned in section 3.3.2, based on Product Category Rules (PCR), the EPD provides a default list of 7 indicators and methods claimed to be the most significant environmental impact KPIs. Given the high number of measures and considering that these have to be integrated into a visual support system (dashboard) there is the need to reduce the number of indicators, selecting the most significant according to the project. For this reason, OEF, PEF and EPD KPIs have been mapped and only the indicators category matching all the 3 standards have been selected to be considered in the framework. Please note that EPD indicators are a subgroup of OEF and PEF ones, so, only EPD KPIs have been considered in the framework. Also, it is important to highlight that every impact indicator will be calculated since the computational effort does not depend on the number of indicators, so, the 7 in the blue cells (see Table 17) are the ones chose to be visualised.

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Table 17: Mapping and selection of impact indicators and characterization models

Impact category	Impact category indicator	Unit	Characterization model	PEF/PEF	EPD
Climate change, total	**Radiative forcing as global warming potential (GWP100)**	**kg CO2 eq.**	Baseline model of 100 years of the IPCC (based on IPCC 2013) / **GWP100, CML 2001 baseline**	**X**	**X**
Ozone depletion	depletion	kg CFC-11 eq.	Steady-state ODPs as in (WMO 2014 + integrations)	X	
Human toxicity, cancer	Comparative Toxic Unit for humans (CTUh)	CTUh	USEtox model 2.1 (Fankte et al, 2017)	X	
Human toxicity, non-cancer	Comparative Toxic Unit for humans (CTUh)	CTUh	USEtox model 2.1 (Fankte et al, 2017)	X	
Particulate matter	Impact on human health	disease incidence	PM method recomended by UNEP (UNEP 2016)	X	
Ionising radiation, human health	Human exposure efficiency relative to U235	kBq U235 eq.	Human health effect model as developed by Dreicer et al. 1995 (Frischknecht et al, 2000)	X	
Photochemical ozone formation, human health	**Tropospheric ozone concentration increase**	**kg NMVOC eq.**	**LOTOS-EUROS model (Van Zelm et al, 2008) as implemented in ReCiPe 2008 / POFP, LOTOS-EUROS as applied in ReCiPe 2008**	**X**	**X**
Acidification	**Accumulated Exceedance (AE)**	mol H+ eq. / **kg SO_2 eq.**	Accumulated Exceedance (Seppälä et al. 2006, Posch et al, 2008) / **AP, CML 2001 non-baseline (fate not included)**	**X**	**X**
Eutrophication, terrestrial	Accumulated Exceedance (AE)	mol N eq.	Accumulated Exceedance (Seppälä et al. 2006, Posch et al, 2008)	X	
Eutrophication, freshwater	**Fraction of nutrients reaching freshwater end compartment (P)**	kg P eq. / **kg PO43- eq.**	EUTREND model (Struijs et al, 2009) as implemented in ReCiPe / **EP, CML 2001 baseline**	**X**	**X**
Eutrophication, marine	Fraction of nutrients reaching marine end compartment (N)	kg N eq.	EUTREND model (Struijs et al, 2009) as implemented in ReCiPe	X	
Ecotoxicity, freshwater	Comparative Toxic Unit for ecosystems (CTUe)	CTUe	USEtox model 2.1 (Fankte et al, 2017)	X	
Land use	Soil quality index 3) Biotic production Erosion resistance Mechanical filtration Groundwater replenishment	Dimensionless kg biotic production kg soil m^3 water m^3 groundwater	Soil quality index based on LANCA (Beck et al. 2010 and Bos et al. 2016)	X	
Water use	**User deprivation potential (deprivation-weighted water consumption)**	**m^3 H_2O eq.**	Available WAter REmaining (AWARE) as recommended by UNEP, 2016 / **AWARE Method: WULCA Recommendations on characterization model for WSF 2015, 2017**	**X**	**X**
Resource use, minerals and metals	**Abiotic resource depletion (ADP ultimate reserves)**	**kg Sb eq.**	CML 2002 (Guinée et al., 2002) and van Oers et al. 2002. / **ADPelements, CML 2001, baseline**	**X**	**X**
Resource use, fossils	**Abiotic resource depletion – fossil fuels (ADP-fossil)26**	**MJ**	CML 2002 (Guinée et al., 2002) and van Oers et al. 2002 / **ADPfossil fuels, CML 2001, baseline**	**X**	**X**

5.3 Economic performance and cost indicators

This chapter aims to synthesize the current knowledge about the most relevant financial indicators in the DENiM project. The DENiM developments drive to digitize processes aiming at achieving better energy efficiency and higher overall performance, for example. Efficiency improvements are assumed and expected across all dimensions of the profit and loss statement: reduced costs (e.g., minimized energy consumption, automated processes, shorter processing times), revenue generation, and improved risk management (e.g., reduced risk by using precise and timely data, less operational issues). The most relevant indicators in the DENiM project can be divided into:

- *Cost indicators* – OPEX and CAPEX
- *Profitability indicators* – especially if the pilot / generic case study aims to analyse the differences before and after DENiM deployment.
    - To approve the DENiM developments, the cost savings should be at least as good as the return target for the capital (investment costs).

The high-level categorization regarding CAPEX and OPEX is presented in Figure 29. As the DENiM project focuses on the development of energy efficiency across the production process, similarly the focus from the business and cost point of view is on the production cost minimization. Production costs can include a variety of expenses, such as labor, raw materials, components, consumables, for example. It should also be taken into account that sub-indicators are typically needed to calculate the lead cost and profitability indicator(s) and KPI(s) – this also has an effect on the selection of the most relevant financial KPIs in DENiM and in DENiM pilots. In addition, there is a strong linkage and many dependencies between process and cost / economic indicators.

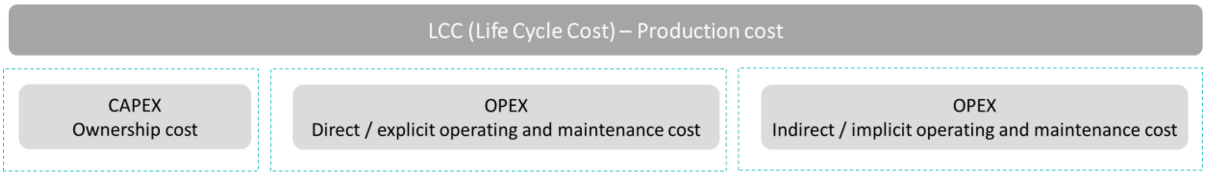

Figure 29: Level 1 cost indicators

CAPEX are major investments and purchases that are designed to be used over the long term. In the DENiM project, especially the investment cost for the DENiM developments as well as the cost of major asset enhancement and replacements during lifetime are of interest Figure 30. When calculating the production costs, CAPEX can be considered as an annualized investment cost and allocated to various processes and further to different machines. Annualized costs are calculated from the total capital cost, the lifetime of the production asset, and the interest rate. Capital costs can be annualized using the Capital Recovery Method (for formula, see Appendix I).

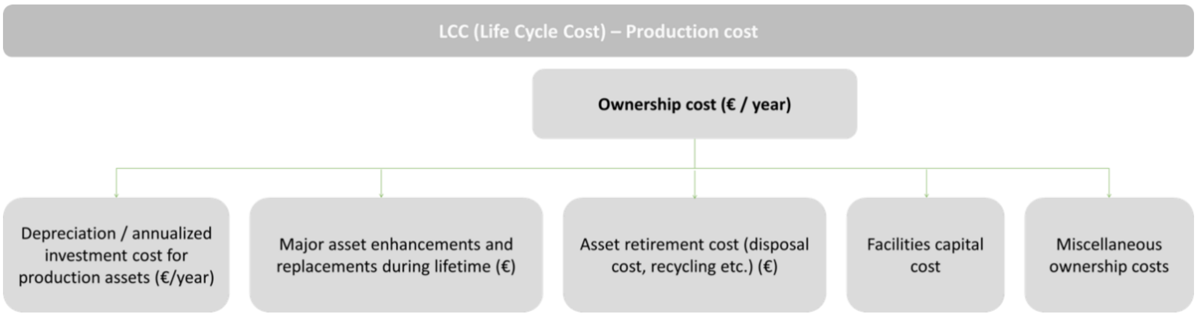

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Figure 30: Level 2 CAPEX indicators

OPEX can be further divided into direct and indirect costs and related indicators. A direct cost is directly tied to the production of specific products or services. Example of indirect costs includes e.g., business interruption cost as it cannot be directly attributed to the production. The most relevant direct operating and maintenance costs for the DENiM project are presented in Figure 31, where the energy cost is the most significant. Energy can be defined as a direct cost since electricity usage increases with the number of products that are manufactured. Electricity costs in production can be reduced by scheduling operations for off-peak-demand hours if possible, upgrading inefficient and outdated equipment, performing scheduled maintenance periodically, and shopping for the best commercial electricity rates, for example. In general, lowering the kW demand while using kWh's for efficient manufacturing helps reduce the cost. There are also options for an energy cost accumulation and assignment in cost accounting that can be applied in the companies depending also on their current cost accounting systems. In the DENiM project, it should be considered how energy cost can be integrated into the elements of life cycle costing.

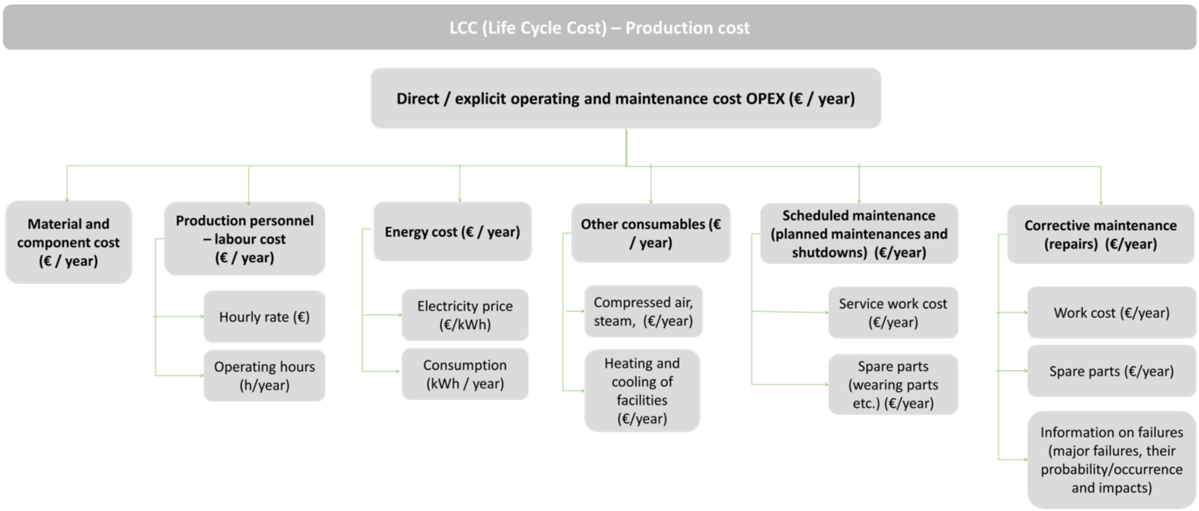


Figure 31: Level 2 OPEX indicators: Direct/explicit operating and maintenance cost indicators relevant for DENiM

A novelty within the DENiM project is especially to explicitly include indirect production costs as well, and to consider, e.g. unavailability as a separate sub-category. This results in three main cost categories, namely: 1. scrap/waste, 2. costs of rework and 3. unavailability cost / lost production and lost revenue. In addition, there are also other indirect impacts, like impacts on the inventory cost (see also Figure 32. The main rational behind distinguishing these cost categories is that they are likely to require different cost assessment methods.

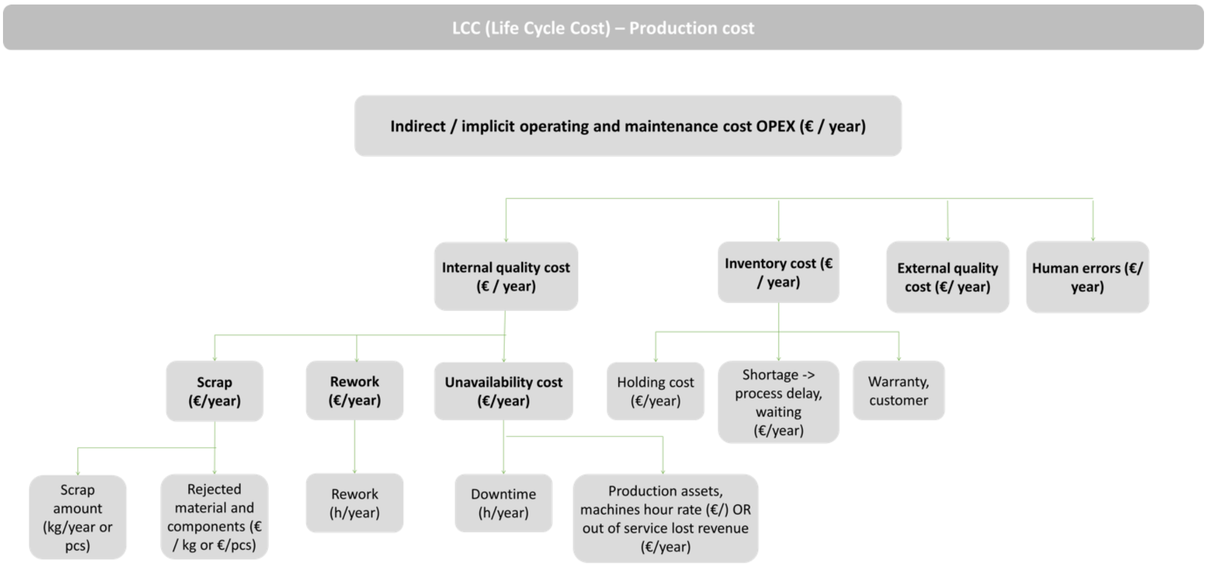


Figure 32: Level 2 OPEX indicators: Indirect/implicit operating and maintenance cost indicators relevant for DENiM

The cost breakdown structure is used to break the main cost categories down into more concrete and more easily estimated cost elements which supports the definition of cost functions to be applied in the calculation of the KPIs in question. It is also important that the developed and applied cost functions are in line with the data that is available and accessible and in a usable form that enables compatibility with the same type of data from different sources. However, typically cost functions need to be tailored to meet the company's needs in practice, in DENiM the needs of the project and its pilots. On a general level, for example, the preventive maintenance cost and the electricity cost can be divided into cost elements as described in Table 18. Appendix I includes generic formulas for most financial indicators in the DENiM project.

Table 18: Example of cost breakdown structuring for the preventive maintenance and electricity cost.

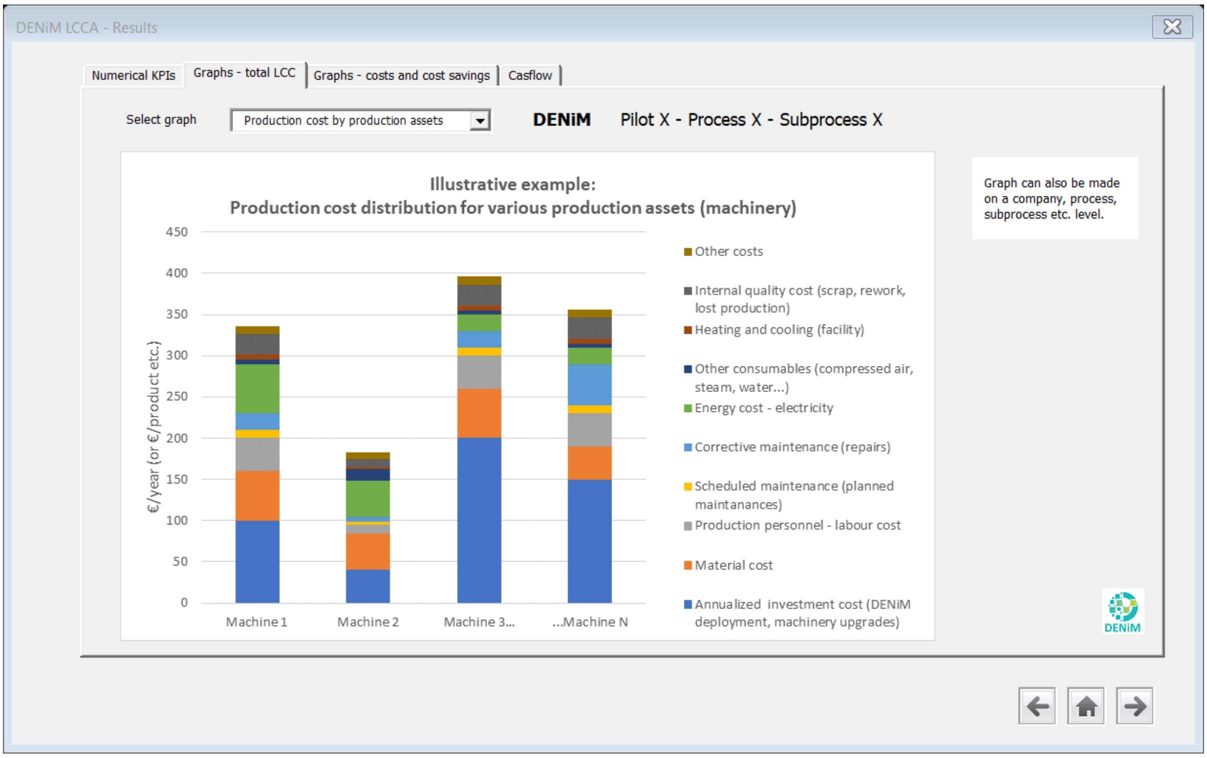
Preventive maintenance [€/year]
- Labor cost [€/task]
  - Work time [hour/prev. maintenance task]
  - Labor cost [€/hour]
  - Spare parts [€/task]
  - Number of preventive maintenance tasks [number/year]
- Travel cost [€/task]
  - Travel distance [km/task]
  - Kilometer allowance [€/km]

Electricity [€/year]
- *Electricity consumption [kWh/year]*
  - Several pilot-specific parameters
- *Electricity price [€/kWh]*

Typically, LCC model is the quantitative model used when comparing decision options. It should be simple enough to be transparent to the user, but accurate enough to represent the difference between options. If the LCCA of one or more DENiM pilots aim to compare decision alternatives, various profitability indicators can be calculated for the DENiM developments:

- life cycle cost (LCC)
    - *Total life cycle costs and cost savings are the sum of discounted costs and cost savings for the calculation period (lifetime).*
- net present value (NPV)
    - *NPV is the difference between the present value of cash inflows and the present value of cash outflows (see Appendix I for more details).*
- payback period (PP), discounted payback period
    - *PP is the length of time required to recover the cost of analyzed solutions. The shorter the pay-back time, the better the solution is.*
- internal rate of return (IRR)
    - *IRR is the discount rate resulting NPV=0. The higher the IRR, the better the solution is according to LCCA.*
- profitability index (PI)
    - *Ratio of NPV of a project divided by the discounted CAPEX.*

Based on the information already available and obtained from the DENiM pilot workshops, the scope of the LCCA of the pilots is to evaluate the production costs of the targeted processes and in some cases also sub-processes and selected products, taking into account the indirect expenses and analysing different time horizons, too. The following figure presents an illustrative example of production cost graph (Figure 33).



Select graph: Production cost by production assets

Graph can also be made on a company, process, subprocess etc. level.

Figure 33: Illustrative example of the production cost graph

It is evident that a wide variety of data – both economic and process related technical data - is required when valuating CAPEX and OPEX and assessing the production cost for the selected processes and/or machines and products. To estimate the life cycle cost, different data collection methods can be applied, mainly depending on data availability and accessibility, and the costs to be analysed. For example, methods that could be used in the DENiM project are:

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a. Using constant values previously defined by the pilot company or other stakeholders, e.g., price for maintenance services or electricity price.
b. Calculating values for cost and other parameters based on the technical details of the process and related production assets, e.g., energy consumption.
c. Estimation of parameter values based on the available statistics, e.g., maintenance interval for various machines.
d. Expert judgements for values without any other data source, e.g. price of unavailability hour.

When conducting the LCCA, it is important to consider that the LCCA result KPIs, both cost and profitability indicators, are presented in a way that allows decision maker(s) to clearly understand both the outcomes and implications of the LCCA. When developing the DENiM LCCA tool, the indicators should be summarized and presented both in numerical and graphical forms.

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6 Conclusions

The objective of this task was to design the framework that will support the different levels of the DENiM platform in the acquisition, elaboration and presentation of the information and data required to optimise the performances of the company under the sustainability perspectives.

To this end the activity, whose main focus was the design of the assessment methodology and the indicators to analyse production performances under the sustainability perspective, started with assessment of methodologies, indicators and reporting frameworks currently adopted in eco-efficient manufacturing. In order to better integrate the developed system of indicators within the overall DENiM context, the input deriving from the platform technologies adopted and from the industrial use cases involved were then integrated.

These preliminary activities led to the definition of a comprehensive list of Environmental and economic indicators that will support companies adopting the DENiM platform in assessing and optimising their performances under these two perspectives.

From the environmental perspective, the main KPIs that have been selected are aligned at inventory level with the Global Reporting Initiative, thus considering waste, emissions, materials, water and energy. At impact indicators level, the KPIs have been selected among the list provided by the EU recognised PEF/OEF methodology, filtered also considering EPD.

On the other side, the most relevant financial indicators for the DENiM project and for the DENiM pilots are the cost (CAPEX, OPEX) and profitability indicators. Especially the KPIs related to the production cost and its sub-costs are of interest. When comparing the situations before and after DENiM developments, in addition to cost KPIs, various profitability indicators can be calculated.

The list of indicators resulting from the work is meant to meet the different needs of the industrial domain either in terms of granularity of the data to be provided and of the indicator to be displayed. The tools developed in the following tasks (T5.4 & T5.5), that will directly integrate the designed framework, will be able therefore to address these different needs by allowing the management and visualisation of indicators according with the different needs and requirements defined in the project and pilots. Table 19 summarize the main environmental (green) and economic (light blue) indicators:

Table 19: Main environmental and economic KPIs

Indicator	Formula	Unit
Total waste generated	-	kg
Waste intensity	$\frac{Total\ waste\ generated\ (kg)}{normalisation\ factor}$	kg/nf
Total emissions	-	kg
Emissions intensity	$\frac{Total\ emissions\ (kg)}{normalisation\ factor}$	kg/nf
Total material input	-	kg
Total material input intensity	$\frac{Total\ material\ input(kg)}{normalisation\ factor}$	kg/nf
Total water intake	-	ML

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Water intensity	$\frac{Total\ water\ intake\ (ML)}{normalisation\ factor}$	ML/nf
Total water discharge	-	ML
Total energy consumption	-	MJ
Energy intensity	$\frac{Total\ energy\ consumption\ (MJ)}{normalisation\ factor}$	MJ/nf
CAPEX	Ownership cost	€
OPEX	Direct/explicit operation and maintenance cost	€
OPEX	Indirect/implicit operating and maintenance cost	€

Based on the research done in DENiM WP3, there are some open questions that still need further discussion and research, as these aspects should also be considered in other active work-packages:

- While a preliminary assessment and testing of the framework at pilots' level has been started and conducted, this has to be further elaborated in order to fine tune it according with the DENiM platform capabilities and pilots' needs. This will be addressed as a continuing review of the framework in WP5;
- There are many process-related indicators that are needed when calculating LCA and LCCA KPIs. It should be considered and further discussed whether these process-related KPIs will be calculated by other DENiM tools or should be included in the LCA and LCCA tools;
- Data availability will strongly affect the possibility of calculating all the indicators proposed in the framework. High level aggregations and/or local assumptions will be considered in order to achieve an acceptable assessment of process impacts. These elaborations will be further analysed within T5.4 and T5.5;
- CAPEX and OPEX should be allocated to production process, sub-processes & asset level, in some cases also to the products, depending on the assessment focus in various DENiM pilots;
- In the case of a comparative analysis, both CAPEX and OPEX for the baseline situation and then for the situation after DENiM deployments need to be defined and assessed. In this case, also the investment and/or development cost related to DENiM developments needs to be considered.

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Appendix

Appendix I: Examples of formulas for calculation of KPIs

Category	Indicator	Formula	Unit
Environmental performance indicators	% of gases affecting carbon footprint	$\frac{GHG\ gases\ (kg)}{Total\ emissions\ (kg)} * 100$	%
	Emissions of ozone depleting substances	-	kg or m^3 of SO_x and NO_x
	% of waste generated	$\frac{total\ waste\ (kg)}{total\ production\ (kg)}$	%
	% of hazardous material	$\frac{hazardous\ materials\ (kg)}{total\ waste\ (kg)} * 100$	%
	% of reusable/recycled materials	$\frac{Mass\ of\ reused/recycled\ materials\ used(kg)}{total\ production\ (kg)} * 100$	%
	% of waste recycled off/on site	$\frac{total\ reused\ waste\ on\ site(kg)}{total\ reused\ waste\ (kg)} * 100$	%
	Renewable energy rate	$\frac{Renewable\ energy\ (MJ)}{Total\ energy\ used\ (MJ)} * 100$	%
	Renewable electric sources rate	$\frac{Renewable\ electric\ energy\ (kWh)}{Total\ electric\ energy\ used\ (kWh)} * 100$	%
	Resource efficiency	$\frac{Number\ of\ useful\ material\ outputs}{Number\ of\ useful\ material\ inputs}$	%
	weight of restricted substances intensity	$\frac{weight\ of\ restricted\ substances\ consumed}{normalisatioin\ factor}$	kg/nf
	Non-renewable materials intensity	$\frac{weight\ of\ non-renewable\ resources\ consumed}{normalisatioin\ factor}$	kg/nf
	Water intensity	$\frac{Total\ water\ intake}{normalisation\ factor}$	m^3/nf
	Energy intensity	$\frac{energy\ consumed\ in\ production\ processes + energy\ consumed\ in\ overhead}{normalisation\ factor}$	MJ/nf
	Natural cover	$\frac{Natural\ cover\ area}{Total\ land\ area}$	%
Energy performance indicators	Cumulative energy demand	Based on LCA methodology	MJ/kg

	non-renewable cumulative energy demand	Based on LCA methodology	MJ/kg
	Fossil energy use	Based on LCA methodology	MJ/kg
	Primary fossil energy use	Based on LCA methodology	MJ/kg
	Secondary energy use	Based on LCA methodology	MJ/kg
	Net energy indicator	Actual energy consumption – energy in input to the process	MJ
	Energy saving potential	$ESP = \frac{(e_{i\ current} - e_{best\ practice})}{e_{i\ current}} * 100$	%
	Energy savings	$Energy\ savings = \frac{-\Delta\beta}{2\alpha - 1} * \frac{E_d}{Q_d}$ α = Q_r/Q_d , utilization index of the production capacity of a process β = $(E_d-E_r)/E_d$, variation index of the energy used by a process Q_d = designed productivity Q_r = actual productivity E_d = designed energy consumption E_r = actual energy consumption	MJ/nf
	Specific energy consumption	$SEC = \frac{E_{total}}{V_{part}}$	MJ/kg
	Total energy consumption	$E_{total} = \sum Energy\ consumed\ by\ each\ company\ sub-system$	MJ
	Energy waste	$(1 - \eta) * Ei$	MJ
	Energy ratio	$\frac{Output\ Energy}{Input\ Energy}$	%
	Energy efficiency (1)	$\frac{E_{current}}{E_{ideal}}$	%
	Energy efficiency (2)	$energy\ efficiency\ (2) = \frac{production\ output}{total\ energy\ input}$	%
	Output renewability	$\frac{Renewable\ energy}{E_{total}} * 100$	%

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Social performance indicators	Rate of employees that are shareholders	$\frac{employees\ that\ are\ shareholders}{total\ employees} * 100$	%
	Employee satisfaction	-	-
	Employee turnover rate	$\frac{Employees\ who\ left}{(Employees\ at\ the\ beginning\ + Employees\ at\ the\ end)/2} * 100$	%
	Accident rate	$\frac{\#\ of\ accident}{timeframe}$	#/month
	Time of employees working in dangerous workplaces	-	h
	Noise level	-	db
	Absenteeism	$\frac{\#\ of\ total\ days\ of\ absence}{\#\ of\ total\ working\ days} * 100$	%
	equality rate	$\frac{\#\ of\ male\ employees}{\#\ of\ female\ employees}$	%
	labour intensity	$\frac{hours\ of\ work}{normalization\ factor}$	h/nf
	% participants in social initiatives	$\frac{\#\ of\ participating\ employees}{\#\ of\ total\ employees}$	%
Economic performance indicators	Return of equity (ROE)	$\frac{Earnings\ After\ Taxes\ (EAT)}{Average\ equity}$	%
	Return on assets (ROA)	$\frac{Earning\ Before\ Interest\ and\ Taxes\ (EBIT)}{Average\ equity}$	%
	Return on sale (ROS)	$ROS = \frac{Earnings\ After\ Taxes\ (EAT)}{Revenue}$	%
	Return on capital employed (ROCE)	$\frac{EBIT}{Equity + long\ term\ liabilities}$	%
	Liquidity	$\frac{Current\ assets}{short\ term\ liabilities}$	€
	Debt	$\frac{Assets}{Liabilities}$	€
	Assets turnover	$\frac{Total\ sales}{\frac{beginning\ assets + ending\ assets}{2}}$	#

	Inventory turnover	$\frac{Cost\ of\ good\ sold}{Average\ value\ fo\ inventory}$	#
	Total cost of ownership	$Purchase + cost\ of\ running + cost\ of\ non\ running$	€
	Productivity	$\frac{Added\ value}{Sales\ of\ own\ products\ and\ services + revenues\ from\ goods}$	%
	Delivery precision	$\frac{In\ time\ deliveries}{total\ deliveries} * 100$	%
	% of money for the purchase from local suppliers	$\frac{Amount\ of\ money\ for\ expenses\ from\ local\ suppliers}{Total\ amount\ of\ money\ for\ expenses\ from\ all\ suppliers} * 100$	%
	Investments in environmental certification (ISO 9001, ISO 14001, ISO 50001, UNE 166002 and OHSAS 18001)	-	€
	Net present value (NPV)	NPV is the difference between the present value of cash inflows and the present value of cash outflow. The investment is profitable if NPV > 0. The higher the NPV, the better the investment is from the economic profitability point of view. $NPV = \frac{R_t}{(1+i)^t}$ t = time of the cash flow i = discount rate R_t = net cash flow	€
	Payback period (PP)	The pay-back period is the length of time required to recover the cost of an investment. The shorter the pay-back time, the better the investment is from the economic profitability point of view. The costs are not discounted. $Payback\ period = \frac{Initial\ Investment}{Annula\ cash\ inflow}$	years
	Discounted payback period (DPP)	The discounted payback period is the amount of time that it takes to cover the cost of an investment, by adding a positive discounted cash flow coming from the benefits of the implementation of an investment. The shorter the pay-back time, the better from the economic profitability point of view. $DPP = \ln(\frac{1}{1-\frac{O_1 * r}{CF}}) \div \ln(1+r)$ O_1 = Initial Investment (Outflow) r = rate CF = Periodic Cash Flow	years
	Internal rate of return (IRR)	The internal rate of return is the discount rate resulting NPV=0. The higher the IRR, the better the investment is from the economic profitability point of view.	%

		$IRR = \sum_{t-1}^{t} \frac{C_t}{(1+r)^t} - C_o$ Where: C_t = Net Cash Inflow During the Period t r = Discount Rate t = Number of Time Periods C_o = Total Initial Investment Cost	
	Return on Investment (ROI)	ROI is calculated by subtracting the initial value of the investment from the final value of the investment (which equals the net return), then dividing this new number (the net return) by the cost of the investment, and, finally, multiplying it by 100. $ROI\ (\%) = \frac{Return\ (profit) - Investment\ (expense)}{Investment\ (expense)} * 100$ OR $ROI\ (\%) = \frac{Net\ Return/Profit}{Investement\ (expense)} * 100$	%
	Present Value of Costs (PVC)	Present value of costs is the estimated current value of a future amount to be received or paid out, discounted at the specified discount rate.	€
	Life Cycle Cost	LCC is the discounted sum of CAPEX, OPEX and lost revenue (income loss that occurs when the generated income are less than expected due to external or internal factors). $LCC = Cic + Cinst + Ce + Co + Cm + Cs + Cd$ Cic = Initial Cost Cinst = Delivery and Installation Costs Ce = Energy Cost Co = Operational cost Cm = Maintenance Costs Cs = Downtime Costs Cd = Decommissioning/disposal costs	€
	Capital expenditures CAPEX	Investment is used to purchase, install and commission an asset	€
	Operating expense OPEX	Expenses used for operation and maintenance, including associated costs such as logistics and spares	€
	Annualized capital cost	$AnnualizedCost = (CRF * Capital\ Cost)$ Where: $CRF = \frac{Rate}{1 - (1 + Rate)^{-life}}$ Capital Cost: total capital cost. Life: a whole number of years Rate: the rate charged on the loan for the capital cost (defaults to the study discount rate).	€

	Overall Equipment Effectiveness (OEE) availability, performance, quality	$OEE = Availability * Performance * Quality$ Where: $Availability = \frac{Planned\ Production\ Hours - Lost\ Time}{Planned\ Production\ Hours}$ $Performance = \frac{Actual\ Machine\ Speed}{Design\ Machine\ Speed}$ $Quality = \frac{Number\ of\ Good\ Products}{Total\ Products\ Made}$	%

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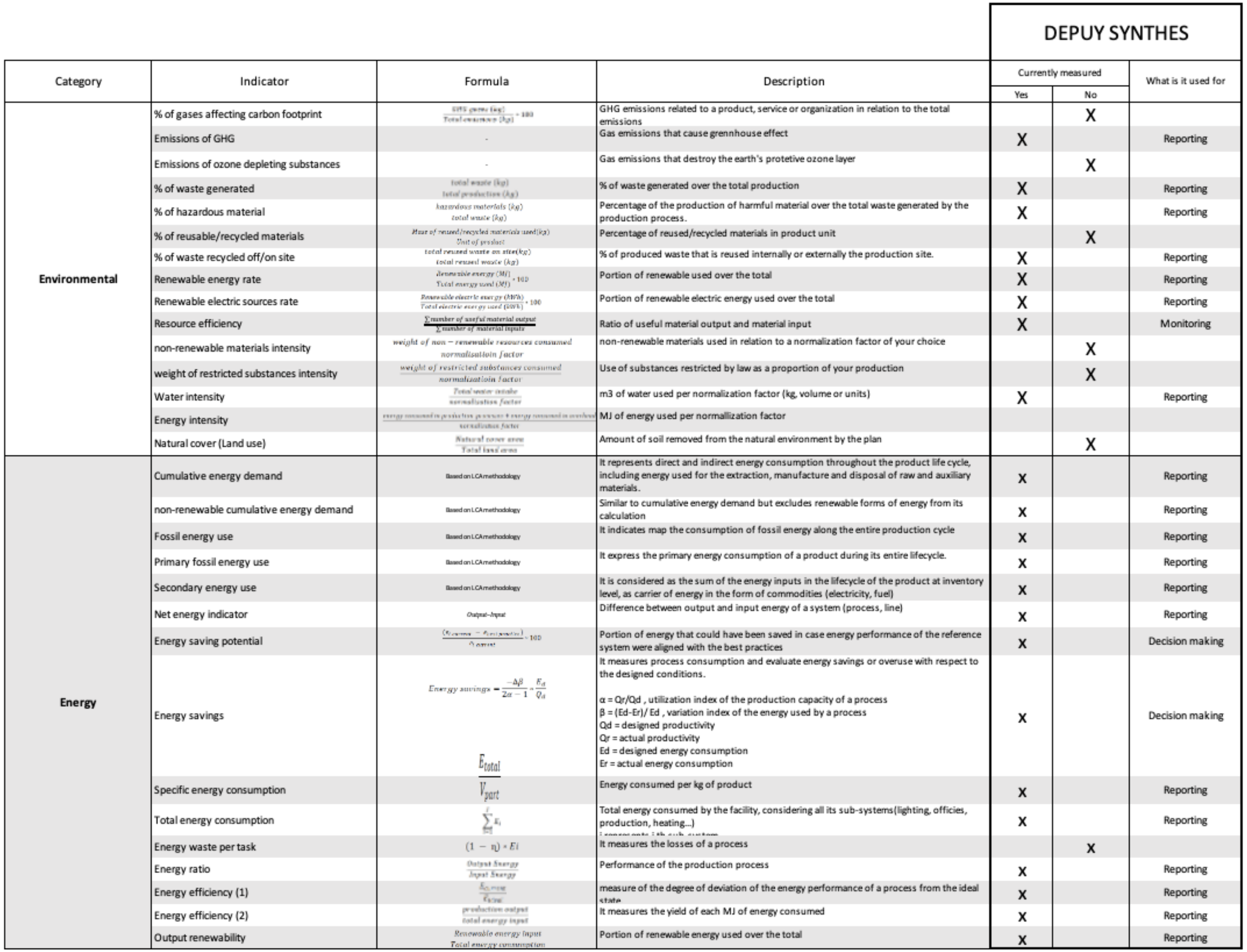
Appendix II: DePuy Synthes mapping of currently measured KPIs



Category	Indicator	Formula	Description	DEPUY SYNTHES		
				Currently measured		What is it used for
				Yes	No	
Environmental	% of gases affecting carbon footprint	$\frac{GHG\ gases\ (kg)}{Total\ emissions\ (kg)} \cdot 100$	GHG emissions related to a product, service or organization in relation to the total emissions		X	
	Emissions of GHG	-	Gas emissions that cause grennhouse effect	X		Reporting
	Emissions of ozone depleting substances	-	Gas emissions that destroy the earth's protetive ozone layer		X	
	% of waste generated	$\frac{total\ waste\ (kg)}{total\ production\ (kg)}$	% of waste generated over the total production	X		Reporting
	% of hazardous material	$\frac{hazardous\ materials\ (kg)}{total\ waste\ (kg)}$	Percentage of the production of harmful material over the total waste generated by the production process.	X		Reporting
	% of reusable/recycled materials	$\frac{Mass\ of\ reused/recycled\ materials\ used(kg)}{Unit\ of\ product}$	Percentage of reused/recycled materials in product unit		X	
	% of waste recycled off/on site	$\frac{total\ reused\ waste\ on\ site(kg)}{total\ reused\ waste\ (kg)}$	% of produced waste that is reused internally or externally the production site.	X		Reporting
	Renewable energy rate	$\frac{Renewable\ energy\ (MJ)}{Total\ energy\ used\ (MJ)} \cdot 100$	Portion of renewable used over the total	X		Reporting
	Renewable electric sources rate	$\frac{Renewable\ electric\ energy\ (kWh)}{Total\ electric\ energy\ used\ (kWh)} \cdot 100$	Portion of renewable electric energy used over the total	X		Reporting
	Resource efficiency	$\frac{\sum number\ of\ useful\ material\ output}{\sum number\ of\ material\ inputs}$	Ratio of useful material output and material input	X		Monitoring
	non-renewable materials intensity	$\frac{weight\ of\ non-renewable\ resources\ consumed}{normalisatioin\ factor}$	non-renewable materials used in relation to a normalization factor of your choice		X	
	weight of restricted substances intensity	$\frac{weight\ of\ restricted\ substances\ consumed}{normalisatioin\ factor}$	Use of substances restricted by law as a proportion of your production		X	
	Water intensity	$\frac{Total\ water\ intake}{normalisation\ factor}$	m3 of water used per normalization factor (kg, volume or units)	X		Reporting
	Energy intensity	$\frac{energy\ consumed\ in\ production\ processes + energy\ consumed\ in\ overhead}{normalisation\ factor}$	MJ of energy used per normallization factor			
	Natural cover (Land use)	$\frac{Natural\ cover\ area}{Total\ land\ area}$	Amount of soil removed from the natural environment by the plan		X	
Energy	Cumulative energy demand	Based on LCA methodology	It represents direct and indirect energy consumption throughout the product life cycle, including energy used for the extraction, manufacture and disposal of raw and auxiliary materials.	X		Reporting
	non-renewable cumulative energy demand	Based on LCA methodology	Similar to cumulative energy demand but excludes renewable forms of energy from its calculation	X		Reporting
	Fossil energy use	Based on LCA methodology	It indicates map the consumption of fossil energy along the entire production cycle	X		Reporting
	Primary fossil energy use	Based on LCA methodology	It express the primary energy consumption of a product during its entire lifecycle.	X		Reporting
	Secondary energy use	Based on LCA methodology	It is considered as the sum of the energy inputs in the lifecycle of the product at inventory level, as carrier of energy in the form of commodities (electricity, fuel)	X		Reporting
	Net energy indicator	Output–Input	Difference between output and input energy of a system (process, line)	X		Reporting
	Energy saving potential	$\frac{(E_{current} - E_{best\ practice})}{E_{current}} \cdot 100$	Portion of energy that could have been saved in case energy performance of the reference system were aligned with the best practices	X		Decision making
	Energy savings	$Energy\ savings = \frac{-\Delta\beta}{2\alpha - 1} \cdot \frac{E_d}{Q_d}$	It measures process consumption and evaluate energy savings or overuse with respect to the designed conditions. α = Qr/Qd , utilization index of the production capacity of a process β = (Ed-Er)/ Ed , variation index of the energy used by a process Qd = designed productivity Qr = actual productivity Ed = designed energy consumption Er = actual energy consumption	X		Decision making
	Specific energy consumption	$\frac{E_{total}}{V_{part}}$	Energy consumed per kg of product	X		Reporting
	Total energy consumption	$\sum_{i=1}^{I} E_i$	Total energy consumed by the facility, considering all its sub-systems(lighting, officies, production, heating…)	X		Reporting
	Energy waste per task	$(1 - \eta) \cdot Ei$	It measures the losses of a process		X	
	Energy ratio	$\frac{Output\ Energy}{Input\ Energy}$	Performance of the production process	X		Reporting
	Energy efficiency (1)	$\frac{E_{i,real}}{E_{ideal}}$	measure of the degree of deviation of the energy performance of a process from the ideal state	X		Reporting
	Energy efficiency (2)	$\frac{production\ output}{total\ energy\ input}$	It measures the yield of each MJ of energy consumed	X		Reporting
	Output renewability	$\frac{Renewable\ energy\ input}{Total\ energy\ consumption}$	Portion of renewable energy used over the total	X		Reporting

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Appendix III: DePuy Synthes mapping of currently used reporting and sustainability assessment methods

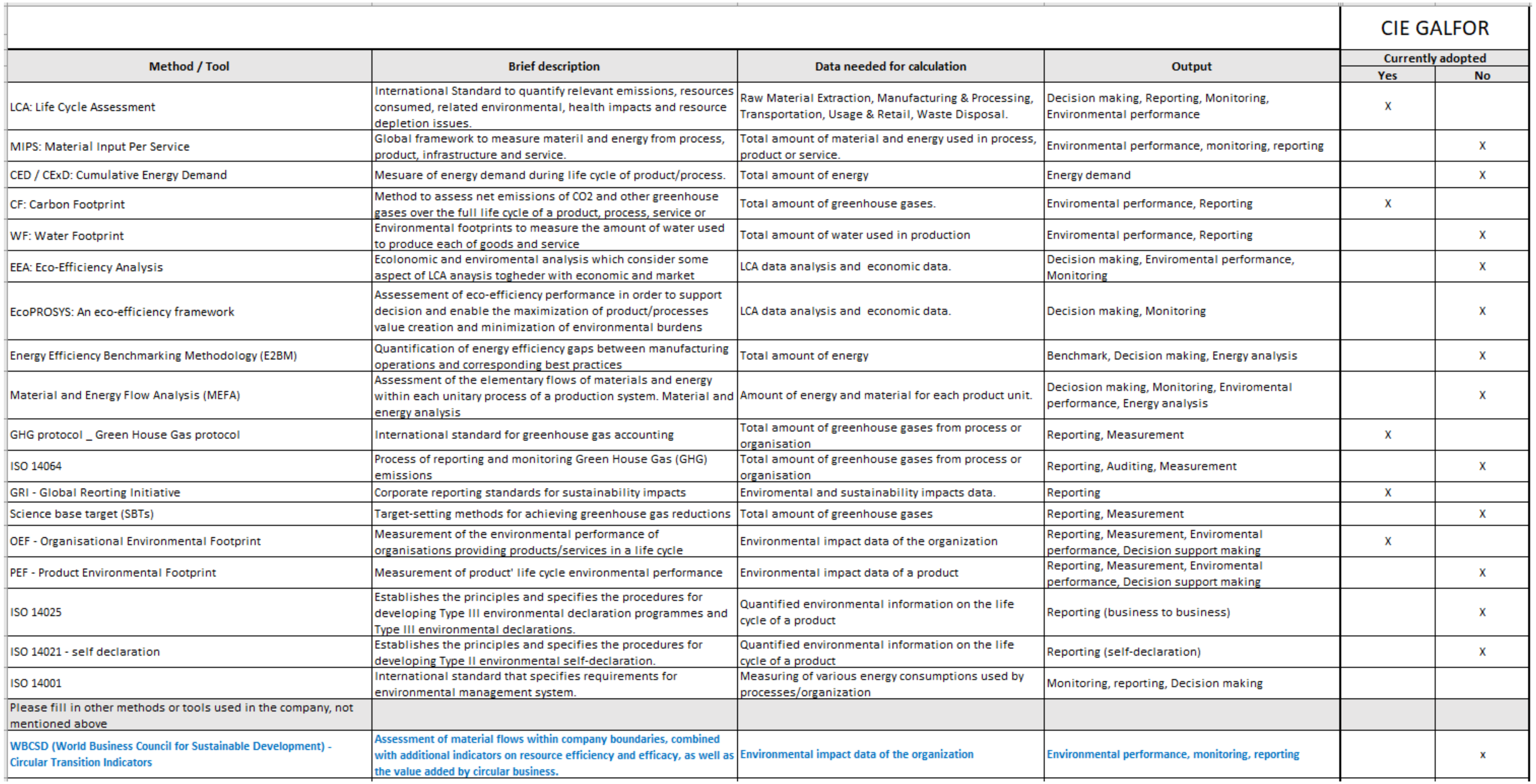
				DEPUY SYNTHES	
Method / Tool	**Brief description**	**Data needed for calculation**	**Output**	**Currently adopted**	
				Yes	**No**
LCA: Life Cycle Assessment	International Standard to quantify relevant emissions, resources consumed, related environmental, health impacts and resource depletion issues.	Raw Material Extraction, Manufacturing & Processing, Transportation, Usage & Retail, Waste Disposal.	Decision making, Reporting, Monitoring, Environmental performance		X
MIPS: Material Input Per Service	Global framework to measure materil and energy from process, product, infrastructure and service.	Total amount of material and energy used in process, product or service.	Environmental performance, monitoring, reporting		X
CED / CExD: Cumulative Energy Demand	Mesuare of energy demand during life cycle of product/process.	Total amount of energy	Energy demand		X
CF: Carbon Footprint	Method to assess net emissions of CO2 and other greenhouse gases over the full life cycle of a product, process, service or	Total amount of greenhouse gases.	Enviromental performance, Reporting	X	
WF: Water Footprint	Environmental footprints to measure the amount of water used to produce each of goods and service	Total amount of water used in production	Enviromental performance, Reporting	X	
EEA: Eco-Efficiency Analysis	Ecolonomic and enviromental analysis which consider some aspect of LCA anaysis togheder with economic and market	LCA data analysis and economic data.	Decision making, Enviromental performance, Monitoring		X
EcoPROSYS: An eco-efficiency framework	Assessement of eco-efficiency performance in order to support decision and enable the maximization of product/processes value creation and minimization of environmental burdens	LCA data analysis and economic data.	Decision making, Monitoring		X
Energy Efficiency Benchmarking Methodology (E2BM)	Quantification of energy efficiency gaps between manufacturing operations and corresponding best practices	Total amount of energy	Benchmark, Decision making, Energy analysis		X
Material and Energy Flow Analysis (MEFA)	Assessment of the elementary flows of materials and energy within each unitary process of a production system. Material and energy analysis	Amount of energy and material for each product unit.	Deciosion making, Monitoring, Enviromental performance, Energy analysis		X
GHG protocol _ Green House Gas protocol	International standard for greenhouse gas accounting	Total amount of greenhouse gases from process or organisation	Reporting, Measurement	X	
ISO 14064	Process of reporting and monitoring Green House Gas (GHG) emissions	Total amount of greenhouse gases from process or organisation	Reporting, Auditing, Measurement		X
GRI - Global Reorting Initiative	Corporate reporting standards for sustainability impacts	Enviromental and sustainability impacts data.	Reporting		X
Science base target (SBTs)	Target-setting methods for achieving greenhouse gas reductions	Total amount of greenhouse gases	Reporting, Measurement		X
OEF - Organisational Environmental Footprint	Measurement of the environmental performance of organisations providing products/services in a life cycle	Environmental impact data of the organization	Reporting, Measurement, Enviromental performance, Decision support making	X	
PEF - Product Environmental Footprint	Measurement of product' life cycle environmental performance	Environmental impact data of a product	Reporting, Measurement, Enviromental performance, Decision support making	X	
ISO 14025	Establishes the principles and specifies the procedures for developing Type III environmental declaration programmes and Type III environmental declarations.	Quantified environmental information on the life cycle of a product	Reporting (business to business)		X
ISO 14021 - self declaration	Establishes the principles and specifies the procedures for developing Type II environmental self-declaration.	Quantified environmental information on the life cycle of a product	Reporting (self-declaration)		X
ISO 14001	International standard that specifies requirements for environmental management system.	Measuring of various energy consumptions used by processes/organization	Monitoring, reporting, Decision making		
Please fill in other methods or tools used in the company, not mentioned above					
WBCSD (World Business Council for Sustainable Development) - Circular Transition Indicators	**Assessment of material flows within company boundaries, combined with additional indicators on resource efficiency and efficacy, as well as the value added by circular business.**	**Environmental impact data of the organization**	**Environmental performance, monitoring, reporting**		

Appendix *IV*: CIE Galfor mapping of currently measured KPIs

Category	Indicator	Formula	Description	CIE GALFOR Currently measured		CIE GALFOR
				Yes	No	What is it used for
Environmental	% of gases affecting carbon footprint	$\frac{\text{GHG gases (kg)}}{\text{Total emissions (kg)}} * 100$	GHG emissions related to a product, service or organization in relation to the total emissions		X	
	Emissions of GHG	-	Gas emissions that cause grennhouse effect	X		Reporting
	Emissions of ozone depleting substances	-	Gas emissions that destroy the earth's protetive ozone layer		X	
	% of waste generated	$\frac{\text{total waste (kg)}}{\text{total production (kg)}}$	% of waste generated over the total production		X	
	% of hazardous material	$\frac{\text{hazardous materials (kg)}}{\text{total waste (kg)}}$	Percentage of the production of harmful material over the total waste generated by the production process.	X		Reporting
	% of reusable/recycled materials	$\frac{\text{Mass of reused/recycled materials used(kg)}}{\text{Unit of product}}$	Percentage of reused/recycled materials in product unit		X	
	% of waste recycled off/on site	$\frac{\text{total reused waste on site(kg)}}{\text{total reused waste (kg)}}$	% of produced waste that is reused internally or externally the production site.		X	
	Renewable energy rate	$\frac{\text{Renewable energy (MJ)}}{\text{Total energy used (MJ)}} * 100$	Portion of renewable used over the total	X		Reporting
	Renewable electric sources rate	$\frac{\text{Renewable electric energy (kWh)}}{\text{Total electric energy used (kWh)}} * 100$	Portion of renewable electric energy used over the total	X		Reporting
	Resource efficiency	$\frac{\sum \text{number of useful material output}}{\sum \text{number of material inputs}}$	Ratio of useful material output and material input			
	non-renewable materials intensity	$\frac{\text{weight of non} - \text{renewable resources consumed}}{\text{normalisatioin factor}}$	non-renewable materials used in relation to a normalization factor of your choice			
	weight of restricted substances intensity	$\frac{\text{weight of restricted substances consumed}}{\text{normalisatioin factor}}$	Use of substances restricted by law as a proportion of your production			
	Water intensity	$\frac{\text{Total water intake}}{\text{normalisation factor}}$	m3 of water used per normalization factor (kg, volume or units)	X		Reporting
	Energy intensity	$\frac{\text{energy consumed in production processes + energy consumed in overhead}}{\text{normalisation factor}}$	MJ of energy used per normallization factor	X		Reporting
	Natural cover (Land use)	$\frac{\text{Natural cover area}}{\text{Total land area}}$	Amount of soil removed from the natural environment by the plan		x	
Energy	Cumulative energy demand	Based on LCA methodology	It represents direct and indirect energy consumption throughout the product life cycle, including energy used for the extraction, manufacture and disposal of raw and auxiliary materials.		X	
	non-renewable cumulative energy demand	Based on LCA methodology	Similar to cumulative energy demand but excludes renewable forms of energy from its calculation		X	
	Fossil energy use	Based on LCA methodology	It indicates map the consumption of fossil energy along the entire production cycle		X	
	Primary fossil energy use	Based on LCA methodology	It express the primary energy consumption of a product during its entire lifecycle.		X	
	Secondary energy use	Based on LCA methodology	It is considered as the sum of the energy inputs in the lifecycle of the product at inventory level, as carrier of energy in the form of commodities (electricity, fuel)		X	
	Net energy indicator	Output–Input	Difference between output and input energy of a system (process, line)		X	
	Energy saving potential	$\frac{(\eta_{current} - \eta_{best\,practice})}{\eta_{current}} * 100$	Portion of energy that could have been saved in case energy performance of the reference system were aligned with the best practices		X	
	Energy savings	$Energy\ savings = \frac{-\Delta\beta}{2\alpha - 1} * \frac{E_d}{Q_d}$	It measures process consumption and evaluate energy savings or overuse with respect to the designed conditions. α = Qr/Qd , utilization index of the production capacity of a process β = (Ed-Er)/ Ed , variation index of the energy used by a process Qd = designed productivity Qr = actual productivity Ed = designed energy consumption Er = actual energy consumption		X	
	Specific energy consumption	$\frac{E_{total}}{V_{part}}$	Energy consumed per kg of product	X		Monitoring
	Total energy consumption	$\sum_{i=1}^{I} E_i$	Total energy consumed by the facility, considering all its sub-systems(lighting, officies, production, heating...) i represents i-th sub-system	X		Monitoring
	Energy waste per task	$(1 - \eta) * Ei$	It measures the losses of a process		X	
	Energy ratio	$\frac{\text{Output Energy}}{\text{Input Energy}}$	Performance of the production process		X	
	Energy efficiency (1)	$\frac{E_{0,ideal}}{E_{actual}}$	measure of the degree of deviation of the energy performance of a process from the ideal state		X	
	Energy efficiency (2)	$\frac{\text{production output}}{\text{total energy input}}$	It measures the yield of each MJ of energy consumed		X	
	Output renewability	$\frac{\text{Renewable energy input}}{\text{Total energy consumption}}$	Portion of renewable energy used over the total	X		Monitoring

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 958339.

Appendix V: CIE Galfor mapping of currently used reporting and sustainability assessment methods



				CIE GALFOR	
Method / Tool	**Brief description**	**Data needed for calculation**	**Output**	**Currently adopted**	
				Yes	**No**
LCA: Life Cycle Assessment	International Standard to quantify relevant emissions, resources consumed, related environmental, health impacts and resource depletion issues.	Raw Material Extraction, Manufacturing & Processing, Transportation, Usage & Retail, Waste Disposal.	Decision making, Reporting, Monitoring, Environmental performance	X	
MIPS: Material Input Per Service	Global framework to measure materil and energy from process, product, infrastructure and service.	Total amount of material and energy used in process, product or service.	Environmental performance, monitoring, reporting		X
CED / CExD: Cumulative Energy Demand	Mesuare of energy demand during life cycle of product/process.	Total amount of energy	Energy demand		X
CF: Carbon Footprint	Method to assess net emissions of CO2 and other greenhouse gases over the full life cycle of a product, process, service or	Total amount of greenhouse gases.	Enviromental performance, Reporting	X	
WF: Water Footprint	Environmental footprints to measure the amount of water used to produce each of goods and service	Total amount of water used in production	Enviromental performance, Reporting		X
EEA: Eco-Efficiency Analysis	Ecolonomic and enviromental analysis which consider some aspect of LCA anaysis togheder with economic and market	LCA data analysis and economic data.	Decision making, Enviromental performance, Monitoring		X
EcoPROSYS: An eco-efficiency framework	Assessement of eco-efficiency performance in order to support decision and enable the maximization of product/processes value creation and minimization of environmental burdens	LCA data analysis and economic data.	Decision making, Monitoring		X
Energy Efficiency Benchmarking Methodology (E2BM)	Quantification of energy efficiency gaps between manufacturing operations and corresponding best practices	Total amount of energy	Benchmark, Decision making, Energy analysis		X
Material and Energy Flow Analysis (MEFA)	Assessment of the elementary flows of materials and energy within each unitary process of a production system. Material and energy analysis	Amount of energy and material for each product unit.	Deciosion making, Monitoring, Enviromental performance, Energy analysis		X
GHG protocol _ Green House Gas protocol	International standard for greenhouse gas accounting	Total amount of greenhouse gases from process or organisation	Reporting, Measurement	X	
ISO 14064	Process of reporting and monitoring Green House Gas (GHG) emissions	Total amount of greenhouse gases from process or organisation	Reporting, Auditing, Measurement		X
GRI - Global Reorting Initiative	Corporate reporting standards for sustainability impacts	Enviromental and sustainability impacts data.	Reporting	X	
Science base target (SBTs)	Target-setting methods for achieving greenhouse gas reductions	Total amount of greenhouse gases	Reporting, Measurement		X
OEF - Organisational Environmental Footprint	Measurement of the environmental performance of organisations providing products/services in a life cycle	Environmental impact data of the organization	Reporting, Measurement, Enviromental performance, Decision support making	X	
PEF - Product Environmental Footprint	Measurement of product' life cycle environmental performance	Environmental impact data of a product	Reporting, Measurement, Enviromental performance, Decision support making		X
ISO 14025	Establishes the principles and specifies the procedures for developing Type III environmental declaration programmes and Type III environmental declarations.	Quantified environmental information on the life cycle of a product	Reporting (business to business)		X
ISO 14021 - self declaration	Establishes the principles and specifies the procedures for developing Type II environmental self-declaration.	Quantified environmental information on the life cycle of a product	Reporting (self-declaration)		X
ISO 14001	International standard that specifies requirements for environmental management system.	Measuring of various energy consumptions used by processes/organization	Monitoring, reporting, Decision making		
Please fill in other methods or tools used in the company, not mentioned above					
WBCSD (World Business Council for Sustainable Development) - Circular Transition Indicators	**Assessment of material flows within company boundaries, combined with additional indicators on resource efficiency and efficacy, as well as the value added by circular business.**	**Environmental impact data of the organization**	**Environmental performance, monitoring, reporting**		x

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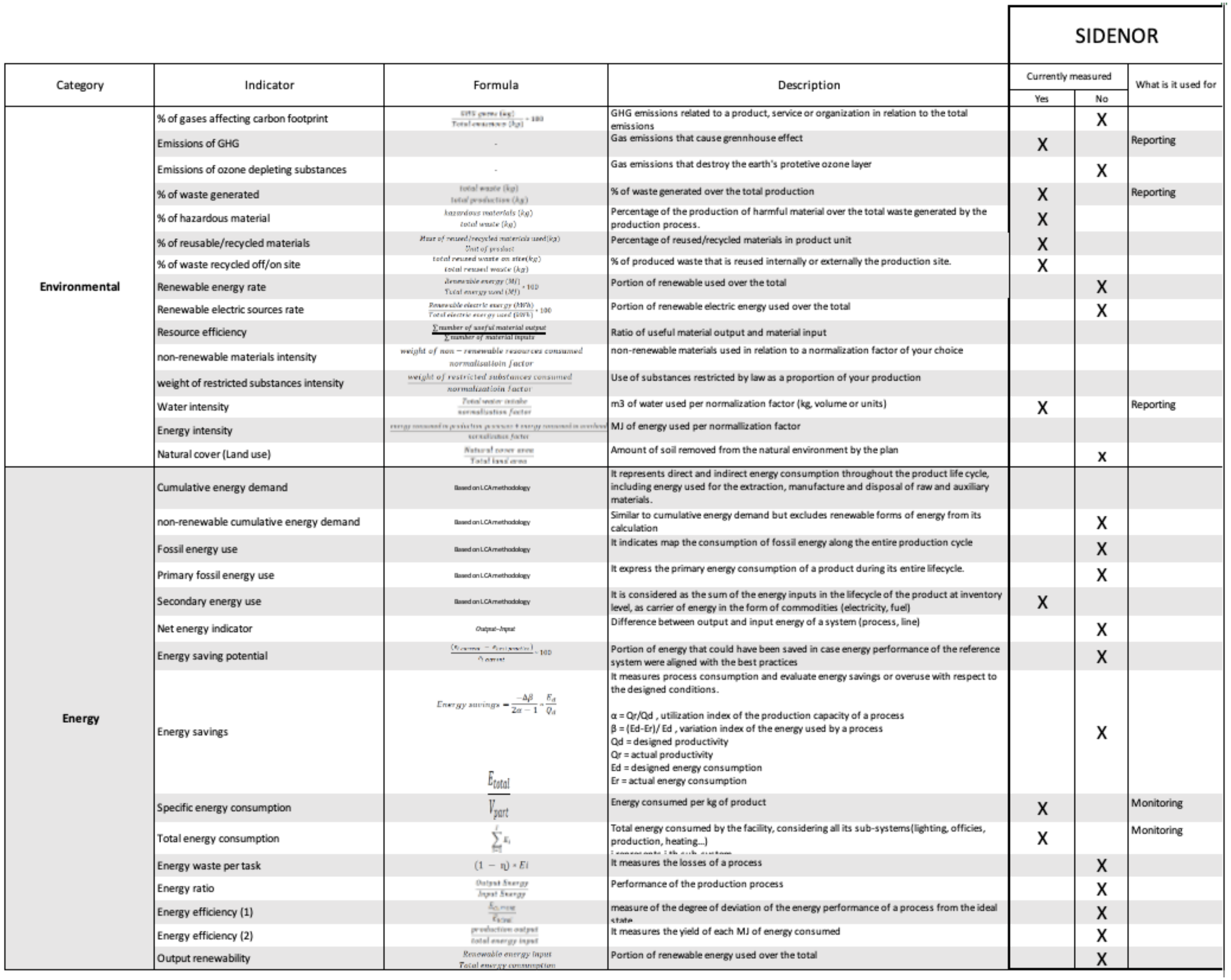
Appendix VI: Sidenor mapping of currently measured KPIs



Category	Indicator	Formula	Description	SIDENOR Currently measured Yes	 No	 What is it used for
Environmental	% of gases affecting carbon footprint	$\frac{GHS\ gases\ (kg)}{Total\ emissions\ (kg)} \cdot 100$	GHG emissions related to a product, service or organization in relation to the total emissions		X	
	Emissions of GHG	-	Gas emissions that cause grennhouse effect	X		Reporting
	Emissions of ozone depleting substances	-	Gas emissions that destroy the earth's protetive ozone layer		X	
	% of waste generated	$\frac{total\ waste\ (kg)}{total\ production\ (kg)}$	% of waste generated over the total production	X		Reporting
	% of hazardous material	$\frac{hazardous\ materials\ (kg)}{total\ waste\ (kg)}$	Percentage of the production of harmful material over the total waste generated by the production process.	X		
	% of reusable/recycled materials	$\frac{Mass\ of\ reused/recycled\ materials\ used(kg)}{Unit\ of\ product}$	Percentage of reused/recycled materials in product unit	X		
	% of waste recycled off/on site	$\frac{total\ reused\ waste\ on\ site(kg)}{total\ reused\ waste\ (kg)}$	% of produced waste that is reused internally or externally the production site.	X		
	Renewable energy rate	$\frac{Renewable\ energy\ (MJ)}{Total\ energy\ used\ (MJ)} \cdot 100$	Portion of renewable used over the total		X	
	Renewable electric sources rate	$\frac{Renewable\ electric\ energy\ (kWh)}{Total\ electric\ energy\ used\ (kWh)} \cdot 100$	Portion of renewable electric energy used over the total		X	
	Resource efficiency	$\frac{\sum number\ of\ useful\ material\ output}{\sum number\ of\ material\ inputs}$	Ratio of useful material output and material input			
	non-renewable materials intensity	$\frac{weight\ of\ non-renewable\ resources\ consumed}{normalisatioin\ factor}$	non-renewable materials used in relation to a normalization factor of your choice			
	weight of restricted substances intensity	$\frac{weight\ of\ restricted\ substances\ consumed}{normalisatioin\ factor}$	Use of substances restricted by law as a proportion of your production			
	Water intensity	$\frac{Total\ water\ intake}{normalisation\ factor}$	m3 of water used per normalization factor (kg, volume or units)	X		Reporting
	Energy intensity	$\frac{energy\ consumed\ in\ production\ processes + energy\ consumed\ in\ overhead}{normalisation\ factor}$	MJ of energy used per normallization factor			
	Natural cover (Land use)	$\frac{Natural\ cover\ area}{Total\ land\ area}$	Amount of soil removed from the natural environment by the plan		x	
Energy	Cumulative energy demand	Based on LCA methodology	It represents direct and indirect energy consumption throughout the product life cycle, including energy used for the extraction, manufacture and disposal of raw and auxiliary materials.			
	non-renewable cumulative energy demand	Based on LCA methodology	Similar to cumulative energy demand but excludes renewable forms of energy from its calculation		X	
	Fossil energy use	Based on LCA methodology	It indicates map the consumption of fossil energy along the entire production cycle		X	
	Primary fossil energy use	Based on LCA methodology	It express the primary energy consumption of a product during its entire lifecycle.		X	
	Secondary energy use	Based on LCA methodology	It is considered as the sum of the energy inputs in the lifecycle of the product at inventory level, as carrier of energy in the form of commodities (electricity, fuel)	X		
	Net energy indicator	Output−Input	Difference between output and input energy of a system (process, line)		X	
	Energy saving potential	$\frac{(E_{current} - E_{best\ practice})}{E_{current}} \cdot 100$	Portion of energy that could have been saved in case energy performance of the reference system were aligned with the best practices		X	
	Energy savings	$Energy\ savings = \frac{-\Delta\beta}{2\alpha - 1} \cdot \frac{E_d}{Q_d}$	It measures process consumption and evaluate energy savings or overuse with respect to the designed conditions. α = Qr/Qd , utilization index of the production capacity of a process β = (Ed-Er)/ Ed , variation index of the energy used by a process Qd = designed productivity Qr = actual productivity Ed = designed energy consumption Er = actual energy consumption		X	
	Specific energy consumption	$\frac{E_{total}}{V_{part}}$	Energy consumed per kg of product	X		Monitoring
	Total energy consumption	$\sum_{i=1}^{i} E_i$	Total energy consumed by the facility, considering all its sub-systems(lighting, officies, production, heating...) i represents i-th sub-system	X		Monitoring
	Energy waste per task	$(1 - \eta) \cdot Ei$	It measures the losses of a process		X	
	Energy ratio	$\frac{Output\ Energy}{Input\ Energy}$	Performance of the production process		X	
	Energy efficiency (1)	$\frac{E_{0,min}}{E_{actual}}$	measure of the degree of deviation of the energy performance of a process from the ideal state		X	
	Energy efficiency (2)	$\frac{production\ output}{total\ energy\ input}$	It measures the yield of each MJ of energy consumed		X	
	Output renewability	$\frac{Renewable\ energy\ input}{Total\ energy\ consumption}$	Portion of renewable energy used over the total		X	

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 958339.

Appendix VII: Sidenor mapping of currently used reporting and sustainability assessment methods

				SIDENOR	
Method / Tool	Brief description	Data needed for calculation	Output	Currently adopted	
				Yes	No
LCA: Life Cycle Assessment	International Standard to quantify relevant emissions, resources consumed, related environmental, health impacts and resource depletion issues.	Raw Material Extraction, Manufacturing & Processing, Transportation, Usage & Retail, Waste Disposal.	Decision making, Reporting, Monitoring, Environmental performance	X	
MIPS: Material Input Per Service	Global framework to measure materil and energy from process, product, infrastructure and service.	Total amount of material and energy used in process, product or service.	Environmental performance, monitoring, reporting	X	
CED / CExD: Cumulative Energy Demand	Mesuare of energy demand during life cycle of product/process.	Total amount of energy	Energy demand		X
CF: Carbon Footprint	Method to assess net emissions of CO2 and other greenhouse gases over the full life cycle of a product, process, service or	Total amount of greenhouse gases.	Enviromental performance, Reporting	X	
WF: Water Footprint	Environmental footprints to measure the amount of water used to produce each of goods and service	Total amount of water used in production	Enviromental performance, Reporting	X	
EEA: Eco-Efficiency Analysis	Ecolonomic and enviromental analysis which consider some aspect of LCA anaysis togheder with economic and market	LCA data analysis and economic data.	Decision making, Enviromental performance, Monitoring		X
EcoPROSYS: An eco-efficiency framework	Assessement of eco-efficiency performance in order to support decision and enable the maximization of product/processes value creation and minimization of environmental burdens	LCA data analysis and economic data.	Decision making, Monitoring		X
Energy Efficiency Benchmarking Methodology (E2BM)	Quantification of energy efficiency gaps between manufacturing operations and corresponding best practices	Total amount of energy	Benchmark, Decision making, Energy analysis		X
Material and Energy Flow Analysis (MEFA)	Assessment of the elementary flows of materials and energy within each unitary process of a production system. Material and energy analysis	Amount of energy and material for each product unit.	Deciosion making, Monitoring, Enviromental performance, Energy analysis	X	
GHG protocol _ Green House Gas protocol	International standard for greenhouse gas accounting	Total amount of greenhouse gases from process or organisation	Reporting, Measurement	X	
ISO 14064	Process of reporting and monitoring Green House Gas (GHG) emissions	Total amount of greenhouse gases from process or organisation	Reporting, Auditing, Measurement		X
GRI - Global Reorting Initiative	Corporate reporting standards for sustainability impacts	Enviromental and sustainability impacts data.	Reporting		X
Science base target (SBTs)	Target-setting methods for achieving greenhouse gas reductions	Total amount of greenhouse gases	Reporting, Measurement		X
OEF - Organisational Environmental Footprint	Measurement of the environmental performance of organisations providing products/services in a life cycle	Environmental impact data of the organization	Reporting, Measurement, Enviromental performance, Decision support making	X	
PEF - Product Environmental Footprint	Measurement of product' life cycle environmental performance	Environmental impact data of a product	Reporting, Measurement, Enviromental performance, Decision support making	X	
ISO 14025	Establishes the principles and specifies the procedures for developing Type III environmental declaration programmes and Type III environmental declarations.	Quantified environmental information on the life cycle of a product	Reporting (business to business)	X	
ISO 14021 - self declaration	Establishes the principles and specifies the procedures for developing Type II environmental self-declaration.	Quantified environmental information on the life cycle of a product	Reporting (self-declaration)		X
ISO 14001	International standard that specifies requirements for environmental management system.	Measuring of various energy consumptions used by processes/organization	Monitoring, reporting, Decision making		
Please fill in other methods or tools used in the company, not mentioned above					
WBCSD (World Business Council for Sustainable Development) - Circular Transition Indicators	**Assessment of material flows within company boundaries, combined with additional indicators on resource efficiency and efficacy, as well as the value added by circular business.**	**Environmental impact data of the organization**	**Environmental performance, monitoring, reporting**		

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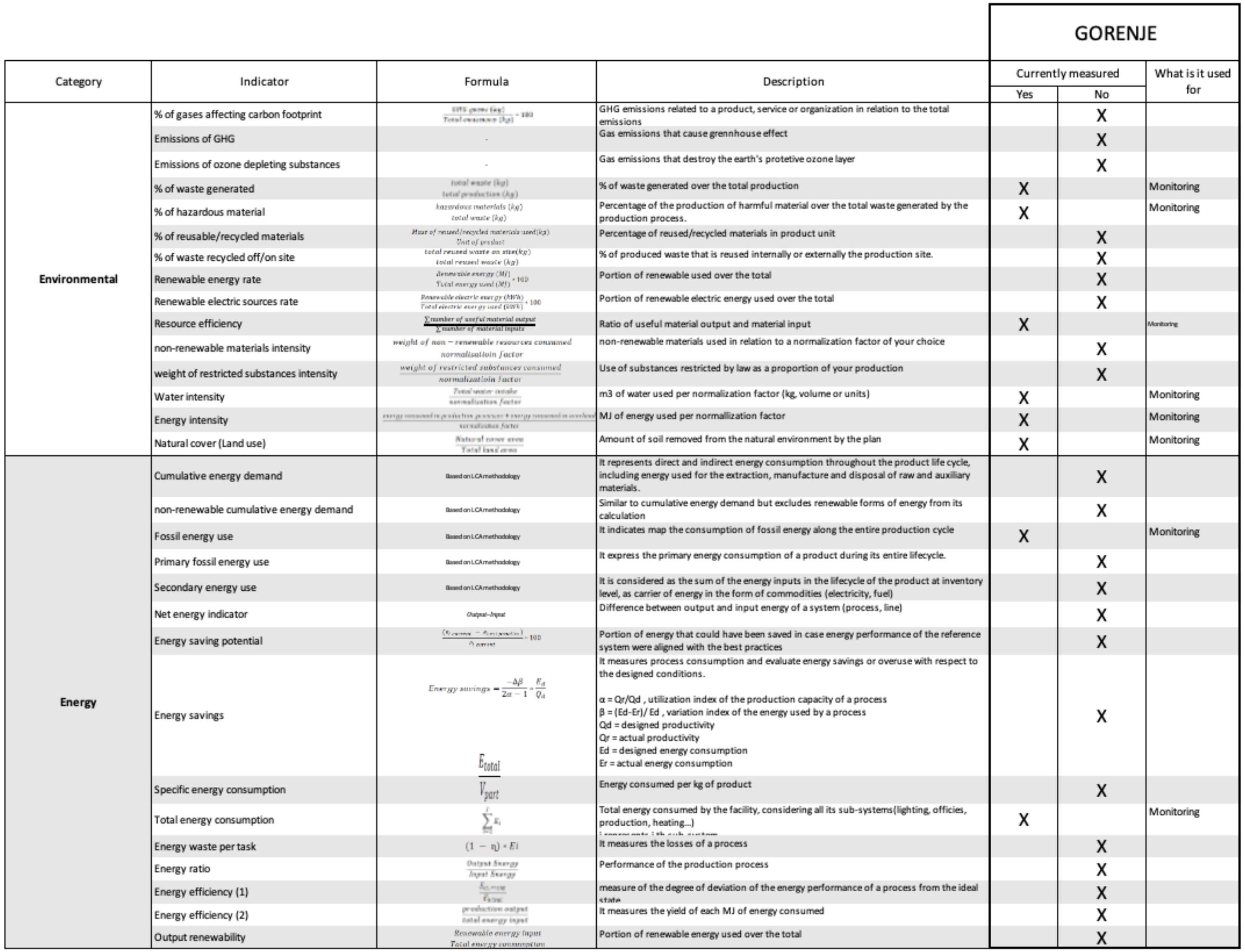
Appendix VIII: Gorenje mapping of currently measured KPIs



				GORENJE		
Category	Indicator	Formula	Description	Currently measured		What is it used for
				Yes	No	
Environmental	% of gases affecting carbon footprint	$\frac{GHG\ gases\ (kg)}{Total\ emissions\ (kg)} \cdot 100$	GHG emissions related to a product, service or organization in relation to the total emissions		X	
	Emissions of GHG	-	Gas emissions that cause grennhouse effect		X	
	Emissions of ozone depleting substances	-	Gas emissions that destroy the earth's protetive ozone layer		X	
	% of waste generated	$\frac{total\ waste\ (kg)}{total\ production\ (kg)}$	% of waste generated over the total production	X		Monitoring
	% of hazardous material	$\frac{hazardous\ materials\ (kg)}{total\ waste\ (kg)}$	Percentage of the production of harmful material over the total waste generated by the production process.	X		Monitoring
	% of reusable/recycled materials	$\frac{Mass\ of\ reused/recycled\ materials\ used(kg)}{Unit\ of\ product}$	Percentage of reused/recycled materials in product unit		X	
	% of waste recycled off/on site	$\frac{total\ reused\ waste\ on\ site(kg)}{total\ reused\ waste\ (kg)}$	% of produced waste that is reused internally or externally the production site.		X	
	Renewable energy rate	$\frac{Renewable\ energy\ (MJ)}{Total\ energy\ used\ (MJ)} \cdot 100$	Portion of renewable used over the total		X	
	Renewable electric sources rate	$\frac{Renewable\ electric\ energy\ (kWh)}{Total\ electric\ energy\ used\ (kWh)} \cdot 100$	Portion of renewable electric energy used over the total		X	
	Resource efficiency	$\frac{\sum number\ of\ useful\ material\ output}{\sum number\ of\ material\ inputs}$	Ratio of useful material output and material input	X		Monitoring
	non-renewable materials intensity	$\frac{weight\ of\ non-renewable\ resources\ consumed}{normalisatioin\ factor}$	non-renewable materials used in relation to a normalization factor of your choice		X	
	weight of restricted substances intensity	$\frac{weight\ of\ restricted\ substances\ consumed}{normalisatioin\ factor}$	Use of substances restricted by law as a proportion of your production		X	
	Water intensity	$\frac{Total\ water\ intake}{normalization\ factor}$	m3 of water used per normalization factor (kg, volume or units)	X		Monitoring
	Energy intensity	$\frac{energy\ consumed\ in\ production\ processes + energy\ consumed\ in\ overhead}{normalization\ factor}$	MJ of energy used per normallization factor	X		Monitoring
	Natural cover (Land use)	$\frac{Natural\ cover\ area}{Total\ land\ area}$	Amount of soil removed from the natural environment by the plan	X		Monitoring
Energy	Cumulative energy demand	Based on LCA methodology	It represents direct and indirect energy consumption throughout the product life cycle, including energy used for the extraction, manufacture and disposal of raw and auxiliary materials.		X	
	non-renewable cumulative energy demand	Based on LCA methodology	Similar to cumulative energy demand but excludes renewable forms of energy from its calculation		X	
	Fossil energy use	Based on LCA methodology	It indicates map the consumption of fossil energy along the entire production cycle	X		Monitoring
	Primary fossil energy use	Based on LCA methodology	It express the primary energy consumption of a product during its entire lifecycle.		X	
	Secondary energy use	Based on LCA methodology	It is considered as the sum of the energy inputs in the lifecycle of the product at inventory level, as carrier of energy in the form of commodities (electricity, fuel)		X	
	Net energy indicator	Output–Input	Difference between output and input energy of a system (process, line)		X	
	Energy saving potential	$\frac{(E_{current} - E_{best\ practice})}{E_{current}} \cdot 100$	Portion of energy that could have been saved in case energy performance of the reference system were aligned with the best practices		X	
	Energy savings	$Energy\ savings = \frac{-\Delta\beta}{2\alpha - 1} \cdot \frac{E_d}{Q_d}$	It measures process consumption and evaluate energy savings or overuse with respect to the designed conditions. α = Qr/Qd , utilization index of the production capacity of a process β = (Ed-Er)/ Ed , variation index of the energy used by a process Qd = designed productivity Qr = actual productivity Ed = designed energy consumption Er = actual energy consumption		X	
	Specific energy consumption	$\frac{E_{total}}{V_{part}}$	Energy consumed per kg of product		X	
	Total energy consumption	$\sum_{i=1}^{I} E_i$	Total energy consumed by the facility, considering all its sub-systems (lighting, offices, production, heating...)	X		Monitoring
	Energy waste per task	$(1 - \eta) \cdot Ei$	It measures the losses of a process		X	
	Energy ratio	$\frac{Output\ Energy}{Input\ Energy}$	Performance of the production process		X	
	Energy efficiency (1)	$\frac{E_{\eta,max}}{E_{actual}}$	measure of the degree of deviation of the energy performance of a process from the ideal state		X	
	Energy efficiency (2)	$\frac{production\ output}{total\ energy\ input}$	It measures the yield of each MJ of energy consumed		X	
	Output renewability	$\frac{Renewable\ energy\ input}{Total\ energy\ consumption}$	Portion of renewable energy used over the total		X	

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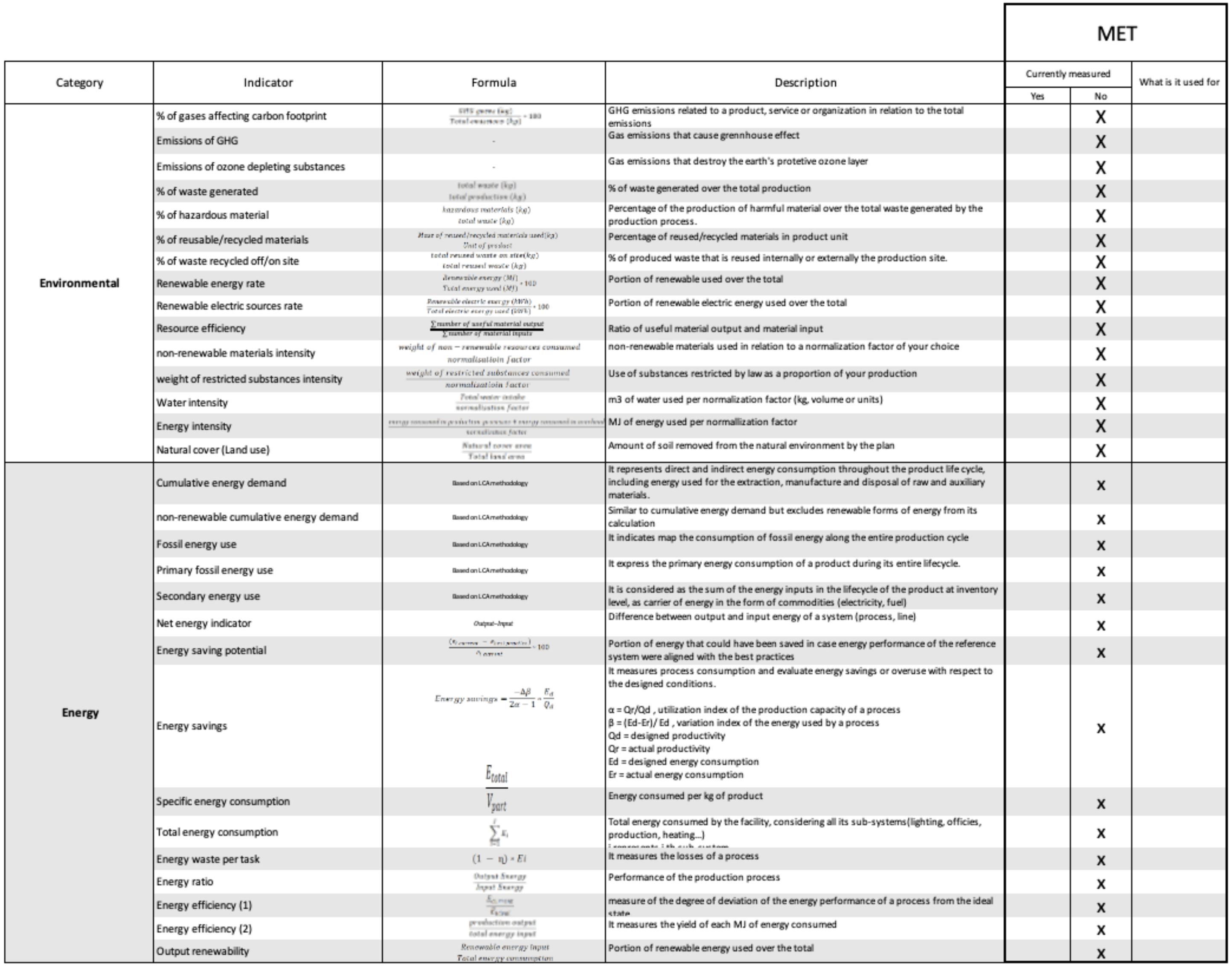
Appendix IX: Gorenje mapping of currently used reporting and sustainability assessment methods

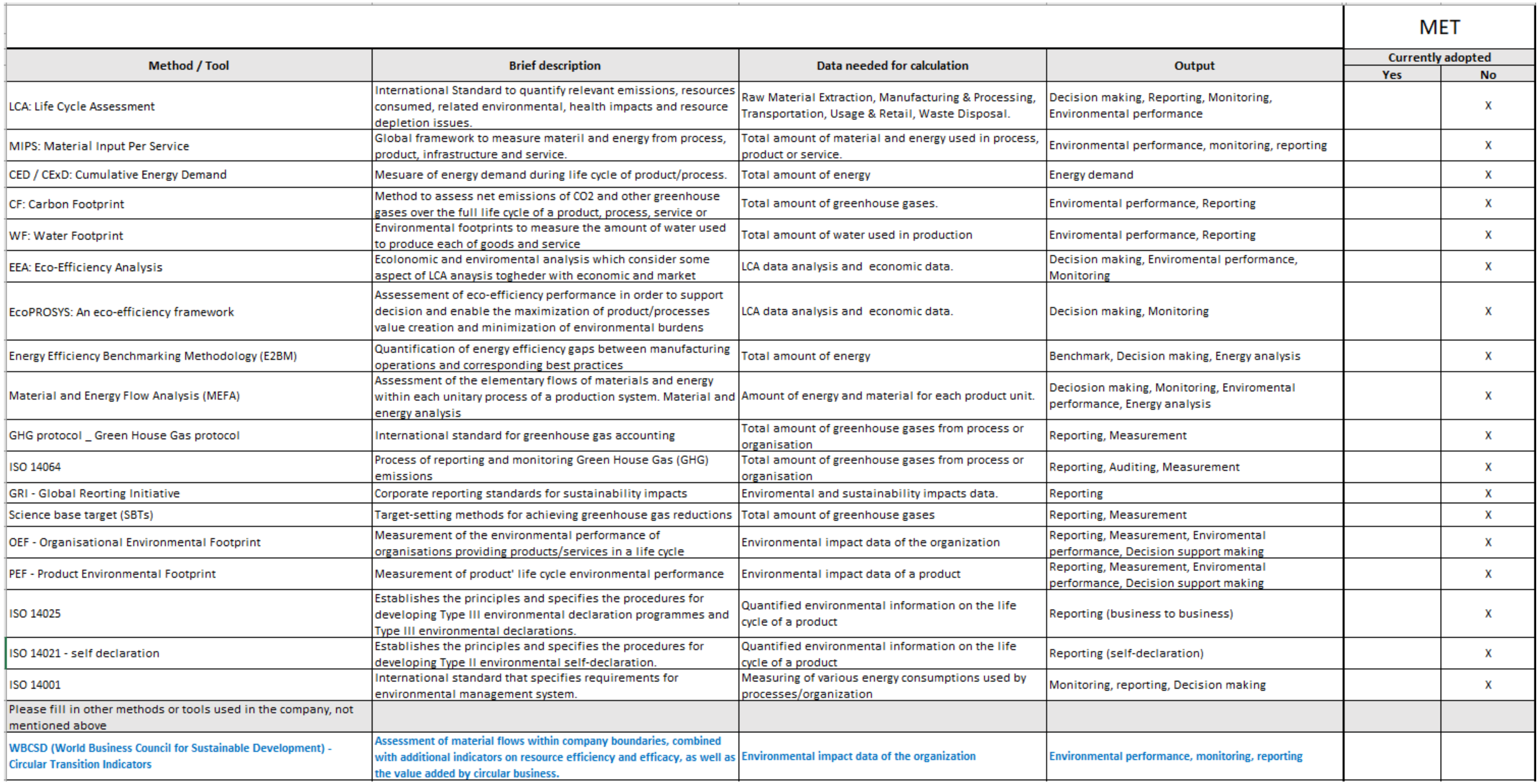
				GORENJE	
Method / Tool	**Brief description**	**Data needed for calculation**	**Output**	**Currently adopted**	
				Yes	**No**
LCA: Life Cycle Assessment	International Standard to quantify relevant emissions, resources consumed, related environmental, health impacts and resource depletion issues.	Raw Material Extraction, Manufacturing & Processing, Transportation, Usage & Retail, Waste Disposal.	Decision making, Reporting, Monitoring, Environmental performance		X
MIPS: Material Input Per Service	Global framework to measure materil and energy from process, product, infrastructure and service.	Total amount of material and energy used in process, product or service.	Environmental performance, monitoring, reporting		X
CED / CExD: Cumulative Energy Demand	Mesuare of energy demand during life cycle of product/process.	Total amount of energy	Energy demand		X
CF: Carbon Footprint	Method to assess net emissions of CO2 and other greenhouse gases over the full life cycle of a product, process, service or	Total amount of greenhouse gases.	Enviromental performance, Reporting		X
WF: Water Footprint	Environmental footprints to measure the amount of water used to produce each of goods and service	Total amount of water used in production	Enviromental performance, Reporting		X
EEA: Eco-Efficiency Analysis	Ecolonomic and enviromental analysis which consider some aspect of LCA anaysis togheder with economic and market	LCA data analysis and economic data.	Decision making, Enviromental performance, Monitoring		X
EcoPROSYS: An eco-efficiency framework	Assessement of eco-efficiency performance in order to support decision and enable the maximization of product/processes value creation and minimization of environmental burdens	LCA data analysis and economic data.	Decision making, Monitoring		X
Energy Efficiency Benchmarking Methodology (E2BM)	Quantification of energy efficiency gaps between manufacturing operations and corresponding best practices	Total amount of energy	Benchmark, Decision making, Energy analysis		X
Material and Energy Flow Analysis (MEFA)	Assessment of the elementary flows of materials and energy within each unitary process of a production system. Material and energy analysis	Amount of energy and material for each product unit.	Deciosion making, Monitoring, Enviromental performance, Energy analysis		X
GHG protocol _ Green House Gas protocol	International standard for greenhouse gas accounting	Total amount of greenhouse gases from process or organisation	Reporting, Measurement		X
ISO 14064	Process of reporting and monitoring Green House Gas (GHG) emissions	Total amount of greenhouse gases from process or organisation	Reporting, Auditing, Measurement		X
GRI - Global Reorting Initiative	Corporate reporting standards for sustainability impacts	Enviromental and sustainability impacts data.	Reporting		X
Science base target (SBTs)	Target-setting methods for achieving greenhouse gas reductions	Total amount of greenhouse gases	Reporting, Measurement		X
OEF - Organisational Environmental Footprint	Measurement of the environmental performance of organisations providing products/services in a life cycle	Environmental impact data of the organization	Reporting, Measurement, Enviromental performance, Decision support making		X
PEF - Product Environmental Footprint	Measurement of product' life cycle environmental performance	Environmental impact data of a product	Reporting, Measurement, Enviromental performance, Decision support making		X
ISO 14025	Establishes the principles and specifies the procedures for developing Type III environmental declaration programmes and Type III environmental declarations.	Quantified environmental information on the life cycle of a product	Reporting (business to business)		X
ISO 14021 - self declaration	Establishes the principles and specifies the procedures for developing Type II environmental self-declaration.	Quantified environmental information on the life cycle of a product	Reporting (self-declaration)		X
ISO 14001	International standard that specifies requirements for environmental management system.	Measuring of various energy consumptions used by processes/organization	Monitoring, reporting, Decision making	X	
Please fill in other methods or tools used in the company, not mentioned above					
WBCSD (World Business Council for Sustainable Development) - Circular Transition Indicators	**Assessment of material flows within company boundaries, combined with additional indicators on resource efficiency and efficacy, as well as the value added by circular business.**	**Environmental impact data of the organization**	**Environmental performance, monitoring, reporting**		

Appendix X: MET mapping of currently measured KPIs



Category	Indicator	Formula	Description	MET Currently measured Yes	MET Currently measured No	MET What is it used for
Environmental	% of gases affecting carbon footprint	$\frac{\text{GHG gases (kg)}}{\text{Total emissions (kg)}} * 100$	GHG emissions related to a product, service or organization in relation to the total emissions		X	
	Emissions of GHG	-	Gas emissions that cause grennhouse effect		X	
	Emissions of ozone depleting substances	-	Gas emissions that destroy the earth's protetive ozone layer		X	
	% of waste generated	$\frac{\text{total waste (kg)}}{\text{total production (kg)}}$	% of waste generated over the total production		X	
	% of hazardous material	$\frac{\text{hazardous materials (kg)}}{\text{total waste (kg)}}$	Percentage of the production of harmful material over the total waste generated by the production process.		X	
	% of reusable/recycled materials	$\frac{\text{Mass of reused/recycled materials used(kg)}}{\text{Unit of product}}$	Percentage of reused/recycled materials in product unit		X	
	% of waste recycled off/on site	$\frac{\text{total reused waste on site(kg)}}{\text{total reused waste (kg)}}$	% of produced waste that is reused internally or externally the production site.		X	
	Renewable energy rate	$\frac{\text{Renewable energy (MJ)}}{\text{Total energy used (MJ)}} * 100$	Portion of renewable used over the total		X	
	Renewable electric sources rate	$\frac{\text{Renewable electric energy (kWh)}}{\text{Total electric energy used (kWh)}} * 100$	Portion of renewable electric energy used over the total		X	
	Resource efficiency	$\frac{\sum \text{number of useful material output}}{\sum \text{number of material inputs}}$	Ratio of useful material output and material input		X	
	non-renewable materials intensity	$\frac{\text{weight of non} - \text{renewable resources consumed}}{\text{normalisatioin factor}}$	non-renewable materials used in relation to a normalization factor of your choice		X	
	weight of restricted substances intensity	$\frac{\text{weight of restricted substances consumed}}{\text{normalisatioin factor}}$	Use of substances restricted by law as a proportion of your production		X	
	Water intensity	$\frac{\text{Total water intake}}{\text{normalisation factor}}$	m3 of water used per normalization factor (kg, volume or units)		X	
	Energy intensity	$\frac{\text{energy consumed in production processes + energy consumed in overhead}}{\text{normalisation factor}}$	MJ of energy used per normallization factor		X	
	Natural cover (Land use)	$\frac{\text{Natural cover area}}{\text{Total land area}}$	Amount of soil removed from the natural environment by the plan		X	
Energy	Cumulative energy demand	Based on LCA methodology	It represents direct and indirect energy consumption throughout the product life cycle, including energy used for the extraction, manufacture and disposal of raw and auxiliary materials.		X	
	non-renewable cumulative energy demand	Based on LCA methodology	Similar to cumulative energy demand but excludes renewable forms of energy from its calculation		X	
	Fossil energy use	Based on LCA methodology	It indicates map the consumption of fossil energy along the entire production cycle		X	
	Primary fossil energy use	Based on LCA methodology	It express the primary energy consumption of a product during its entire lifecycle.		X	
	Secondary energy use	Based on LCA methodology	It is considered as the sum of the energy inputs in the lifecycle of the product at inventory level, as carrier of energy in the form of commodities (electricity, fuel)		X	
	Net energy indicator	Output–Input	Difference between output and input energy of a system (process, line)		X	
	Energy saving potential	$\frac{(\eta_{current} - \eta_{best\,practice})}{\eta_{current}} * 100$	Portion of energy that could have been saved in case energy performance of the reference system were aligned with the best practices		X	
	Energy savings	$Energy\ savings = \frac{-\Delta\beta}{2\alpha - 1} * \frac{E_d}{Q_d}$	It measures process consumption and evaluate energy savings or overuse with respect to the designed conditions. α = Qr/Qd , utilization index of the production capacity of a process β = (Ed-Er)/ Ed , variation index of the energy used by a process Qd = designed productivity Qr = actual productivity Ed = designed energy consumption Er = actual energy consumption		X	
	Specific energy consumption	$\frac{E_{total}}{V_{part}}$	Energy consumed per kg of product		X	
	Total energy consumption	$\sum_{i=1}^{I} E_i$	Total energy consumed by the facility, considering all its sub-systems(lighting, officies, production, heating...) i represents i-th sub-system		X	
	Energy waste per task	$(1 - \eta) * Ei$	It measures the losses of a process		X	
	Energy ratio	$\frac{\text{Output Energy}}{\text{Input Energy}}$	Performance of the production process		X	
	Energy efficiency (1)	$\frac{E_{0,min}}{E_{total}}$	measure of the degree of deviation of the energy performance of a process from the ideal state		X	
	Energy efficiency (2)	$\frac{\text{production output}}{\text{total energy input}}$	It measures the yield of each MJ of energy consumed		X	
	Output renewability	$\frac{\text{Renewable energy input}}{\text{Total energy consumption}}$	Portion of renewable energy used over the total		X	

Appendix XI: MET mapping of currently used reporting and sustainability assessment methods



				MET	
Method / Tool	**Brief description**	**Data needed for calculation**	**Output**	**Currently adopted**	
				Yes	**No**
LCA: Life Cycle Assessment	International Standard to quantify relevant emissions, resources consumed, related environmental, health impacts and resource depletion issues.	Raw Material Extraction, Manufacturing & Processing, Transportation, Usage & Retail, Waste Disposal.	Decision making, Reporting, Monitoring, Environmental performance		X
MIPS: Material Input Per Service	Global framework to measure materil and energy from process, product, infrastructure and service.	Total amount of material and energy used in process, product or service.	Environmental performance, monitoring, reporting		X
CED / CExD: Cumulative Energy Demand	Mesuare of energy demand during life cycle of product/process.	Total amount of energy	Energy demand		X
CF: Carbon Footprint	Method to assess net emissions of CO2 and other greenhouse gases over the full life cycle of a product, process, service or	Total amount of greenhouse gases.	Enviromental performance, Reporting		X
WF: Water Footprint	Environmental footprints to measure the amount of water used to produce each of goods and service	Total amount of water used in production	Enviromental performance, Reporting		X
EEA: Eco-Efficiency Analysis	Ecolonomic and enviromental analysis which consider some aspect of LCA anaysis togheder with economic and market	LCA data analysis and economic data.	Decision making, Enviromental performance, Monitoring		X
EcoPROSYS: An eco-efficiency framework	Assessement of eco-efficiency performance in order to support decision and enable the maximization of product/processes value creation and minimization of environmental burdens	LCA data analysis and economic data.	Decision making, Monitoring		X
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Please fill in other methods or tools used in the company, not mentioned above					
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