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Management System for Process Industries

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Resource and Energy Efficiency



Total Resource and Energy Efficiency Management System for Process Industries



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1 Executive Summary

The MAESTRI project aims to advance the sustainability of European manufacturing and process industries, providing a management system in the form of a flexible and scalable platform, guiding and simplifying the implementation of an innovative approach, the Total Efficiency Framework. The overall aim of this framework is to support the improvement of companies' environmental and economic performance.

Aiming to support the assessment of the companies' efficiency and eco-efficiency, the MAESTRI work package 2 (Efficiency Framework) aims to provide an Efficiency Framework, based on the integration of the Multilayer Stream Mapping – MSM approach, that enables the assessment of the overall efficiency performance of processes, with ecoPROSYS methodology, that assesses eco-efficiency performance through a life cycle perspective.

This document presents the preliminary results using the Efficiency Framework to assess efficiency and eco-efficiency, and ultimately the TEI, of a metalworking company. MSM was applied to company from the chemical sector, in order to test the tool and validate the results.

The results presented in this document will serve to assure that the Efficiency Framework developed in Task 2.2 (see Deliverable 2.2 - Methods for Efficiency Framework for resource and energy efficiency description) is a valid framework, and it is applicable to any process industry regardless the type of industry, sector and size. Due to confidentiality issues, all data and results, presented are factorized, therefore distorted from the real figures of the demo companies. Nevertheless, this distortion does not diminish the quality of the results and the achievement of a first validation to the Efficiency Framework.

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List of Acronyms

BPCM – Process Based Cost Modelling

ecoPROSYS - Eco-Efficiency Integrated Methodology for Production Systems

EPE – Environmental Performance Evaluation

LCA – Life Cycle Assessment

Min. - Minute

MSM - Multi-Layer Stream Mapping

MTEF – MAESTRI Total Efficiency Framework

NVA - Non value-added

QC – Quality check

TEI – Total Efficiency Index

Tot. – Total

VA - Value-added

2 Introduction

The main goal of WP2 is to develop the Efficiency Framework, which encompasses: i) eco-efficiency (environmental influence and economic performance), ii) resource and energy efficiency; and iii) overall efficiency assessment. This Efficiency Framework aims to facilitate the overall efficiency performance assessment of complex systems (such as process production systems) by an integrated multi-dimensional analysis (resource efficiency, operation efficiency, eco-efficiency, etc.) that allows an objective and clear balance assessment between the eco-efficiency and the overall efficiency of a production system.

The Efficiency Framework (as described in D2.1, D2.2 and D2.3) was developed considering a multi-level approach, enabling the assessment of different levels of complexity and different depth of analysis. The framework was also developed in order to be adequate to any process industry regardless the type of industry/sector and size. Yet, tests and analytical validation of the efficiency framework are required to assure the framework is suited to any process industry, and is adaptiveness for the specific needs and capabilities of the pilot implementations.

Therefore, the main goal of this document is to present the performed preliminary tests and respective results, and analytical validation of the efficiency framework for some of the demo cases of MAESTRI. On one hand, by comparing the results of framework with the “conventional” methodologies for the same data input, i.e., perform a simple sensitivity analysis, on the other hand by performing assessments of the real industrial case studies using the Efficiency Framework.

The assessments and validations that take place in this document refer to a part of MAESTRI industrial case studies, as the ultimate and full validation of the framework will be done with more detail, for all industrial use cases in WP6, where physical pilot demonstrations will take place.

It is important to mention that due to confidentiality issues, all data, and consequently the results, presented in the next chapters are factorized. Yet, such factorization of data and results does not affect the quality and the rationality of the results nor the validity of the tests and validations performed to the Efficiency Framework. Additionally, the names of the products, process steps and equipment's are generic also due top confidentiality issues.

This deliverable is organized as follows:

- Chapter 3 presents the identification of the conventional methodologies to be compared with the Efficiency Framework results. Results for both, “conventional” methodologies and Efficiency Framework are presented and compared.
- Chapter 4 provides and discusses the preliminary results from the assessments of the real industrial case studies using the Efficiency Framework for a company from the chemical sector and a metalworking company. The assessment for the company from the chemical sector focuses on testing MSM, while the preliminary results presented for the metalworking company focuses on testing the Efficiency Framework (ecoPROSYS and MSM) in order to obtain eco-efficiency and efficiency stand-alone results, as well as the Total Efficiency Index (TEI).

- Chapter 5 provides a conclusion and major remarks regarding the validation of the Efficiency Framework and discuss the preliminary results from the assessments using the Efficiency Framework.

3 Tests and analytical validation of the efficiency framework

The Efficiency Framework is materialised by the integration of ecoPROSYS and MSM, such integration enables to obtain stand-alone results regarding eco-efficiency and efficiency performance, respectively, as well as, integrated results, namely the Total Efficiency Index.

Moreover, ecoPROSYS encompasses three main modules, the Environmental Performance Evaluation (EPE), Life Cycle Assessment (LCA), and Cost and Value Assessment/Process Based Cost Model (PBCM). In this section of the document, the results obtained from the LCA module from ecoPROSYS will be compared with results from SimaPro, which is a conventional tool used to perform LCA.

Regarding MSM, as the methodology focuses on the overall efficiency and performance assessment of production systems, there is a great similarity between MSM and VSM, as both approaches identify and quantify, at each stage of the production system what adds value and what does not to a product or service. Therefore, Value Stream Mapping results will be compared with MSM results.

The analytical validations for ecoPROSYS and MSM will be performed using real data from industrial case studies namely companies from the chemical and metalworking sector.

3.1 The “conventional” methodologies

As mentioned previously, the LCA module, from ecoPROSYS, will be compared with SimaPro. The analytical validation, of ecoPROSYS, will focus on the LCA, since the EPE and Cost and Value Assessment do not need analytical validation as these are methods already aligned with conventional methods, namely ISO 14031:2013, and the Cost and Value Assessment. LCA enables the quantification of the environmental influence generated by the different elementary flows of the system, is determined through the implementation of a life cycle perspective. LCA is defined as the "compilation and evaluation of the inputs, outputs and potential environmental impacts of a product system throughout its life cycle" (ISO, 2006a). The main advantage of implementing a life cycle perspective is to provide an overall view of the environmental influence of the system, avoiding the shift of problem from one stage to another.

For the LCA analytical validation several tests have been performed to assess and compared, both quantitative and qualitatively, the results from the ecoPROSYS LCA module and the conventional available tools. For specific this purpose the SIMAPRO software has been used. SIMAPRO is the world's leading LCA software and, as a professional tool, allows to collect sustainability data and to analyse and monitor the sustainability performance of company's products and services. Its main purpose is to provide a strong basis for life cycle assessment implementation but, currently, it is also being used for sustainability reporting, carbon and

water foot print, product design, generating environmental product declarations, determining key performance indicators, among others.

The VSM will be considered for the analytical validation of MSM. VSM, is a lean tool used to visualize the product or service flow. The tool consists of a representative flow diagram that enables the identification of inefficient processes that have room for improvement in order to increase the final value delivered to the client (Wilson, 2013). Lean tools, like VSM, enable companies to focus on the value added activities, and to consequently identify waste, leading to the introduction of a culture of continuous improvement (Haefner et al., 2014, Shook and Rother, 1999).

One of the major goals of VSM diagram is to determine, and clearly distinguish, the productive and non-productive time among the production of a given product or during a service provision. The "productive time" should be interpreted as the time needed for the process to occur (time required to add value). The "non-productive time" is the time spent on transport and waiting (time that adds no value, this is, waste, to the product or service). Besides the productive and non-productive time of processes / services, the VSM also considers material flows and information flows inherent to the production system (such as work in progress quantification and other stock figures analysis).

There is a great similarity between MSM and VSM, as both approaches identify and quantify, at each stage of the production system (unit process/processes steps), what adds value and what does not to a product or service. Additionally, MSM takes into account the base design elements and foundations of VSM.

MSM follows the VSM logics, and gives an overview of value and waste elements (i.e. efficiency). In addition, MSM overcomes some of the shortcomings of VSM, in particular it was designed to enable an overall efficiency assessment of production systems and the single process steps, which is not possible with VSM. Additionally, the MSM, provides the means to evaluate the costs related to misapplications and inefficiencies in a disaggregated form (valuable costs and wasteful costs).

3.2 Tests and validation of the Efficiency Framework

Analytical validations for ecoPROSYS LCA module

The tests and analytical validation, as mentioned, will take into account real data (that was factorized). For the results assessment and comparison, a comprehensive set of parameters has been used, including not only the quantitative results, but also its usability, the presentation and the ability of modelling the results.

With this in mind, one important remark should be prior highlighted. The main aim of providing a LCA module is to expand the application spectrum of the tools, once that most companies, and SMEs in particular, are not able to properly implement LCA procedures on frequent basis. Then, by providing a specific module to generate environmental influence and, in particular, to quantify the environmental influence of processes, services and products, MAESTRI intends to fill this gap. However, this module runs over a database developed specifically for this purpose, representing conversion factors for the different input and output flows, including only free available Life Cycle Inventory (LCI) databases. In practice, this means that commercial

available software's are clearly more complete in terms of substances, processes and products covered by their databases, which are also frequently related to considerable additional costs.

This becomes evident by comparing quantitatively the number of LCI datasets available in both ecoPROSYS LCA module and the SIMAPRO software available database. On this, while LCA module presents near 5500 datasets, which is definitely remarkable for a free usable tool, the SIMAPRO software presents more than 14700 entries on the database.

Then, for companies with higher levels of maturity concerning LCA methods implementation (i.e. with previous experience on LCA), the environmental influence module includes a platform where participants may directly import results from an LCA performed in an external software. Considering its widespread application, as well as the amount of market available software and mainly the databases for LCA purposes, this will always represent the most accurate way to assess production system environmental influence.

Regarding the assessment and comparison of results, the analysis has showed a complete alignment. As previously referred, several iterations have been performed on this purpose comparing the results of both tools, in quantitative terms, using different impact categories, damage categories and life cycle impact assessment (LCIA) methods. As some examples of this analysis the next table presents the obtained results for some of the datasets shared by both databases.

Table 1 – Example of results obtained on the quantitative comparison of results

Dataset	LCIA method & Category	SIMAPRO result	ecoPROSYS result
Sodium hydroxide, chlor-alkali production mix, at plant/RER (Ecoprofiles Plastics Europe 2011-2015)	ReCiPe Endpoint (E)/ Europe E/A – Human Health (Pt)	0.0383	0.0383
Steel hot dip galvanized (ILCD), blast furnace route, production mix, at plant, 1kg, typical thickness between 0.3 - 3 mm. typical width between 600 - 2100 mm. GLO S	Ecological Scarcity 2013 – Mineral resources (UBP)	202	202
Polybutadiene granulate (PB), production mix, at plant RER (ELCD)	IMPACT 2002+ - Carcinogens (kg C ₂ H ₃ Cl)	5.15 E-7	5.152E-7
Expandable polystyrene (EPS), white and grey/EU-27 (Ecoprofiles Plastics Europe 2011-2015)	Greenhouse gas protocol – Fossil CO ₂ eq. (kg CO ₂ eq.)	2.36	2.361

On its usability, presentation and the ability of modelling the results, some important differences have been detected. In terms of usability, the ecoPROSYS LCA module is clearly more user friendly regarding the definition and selection of LCIA methods and categories to be used. While SIMAPRO, and other available LCA software, are usually limited to the selection of one specific method, the LCA modules presents a much simpler approach, allowing the definition of different environmental influence methods, together with different impact and damage categories within the same analysis. To perform this ability on available LCA software, it involves a complex process of extracting all required methods, only conducted by the most experienced practitioners, in order to create a specific LCIA method compiling only the intended categories.

In addition, the modelling approach also presents some considerable differences. Generally, to understand and assess the influence of each process parameter within a LCA software, usually requires specific functionalities and modelling approaches regarding the way how the different process datasets are combined. On this purpose, the LCA module of ecoPROSYS, apart from presenting these results in an intuitive manner, it also provides their compilation in terms of environmental aspects, including:

- Materials consumption;
- Energy Consumption;
- Air emissions;
- Water emissions;
- Soil emissions;
- Residues; and,
- Equipment and Infrastructure;

In practice, this means that the different process parameters are grouped considering these categories, which can be expanded in order to assess and present the results of the related/intrinsic process parameters. This is clearly an innovative way which allows to model the LCA results which none of the existing LCA software is currently providing.

Finally, regarding the presentation of results the LCA module of ecoPROSYS also provides the ability of compiling the different process parameters on the existing unit processes considered in the analysis. With this, the user is able to assess and understand the influence of each unit process, in environmental terms, without any additional effort. Comparing to SIMAPRO, and other available LCA software, in which it involves conducting as much as LCIA analysis as the number of unit processes, this is also a clear advantage.

Analytical validations for MSM

Regarding the tests and validation of MSM, the VSM, for two process steps – Laser cutting and bending, of a Metalworking company, is presented and compared with the results obtained by using MSM. In fact, when presenting the VSM and MSM results, for the “time” variable it is foreseen that there will be no deviations, as MSM’s first and mandatory value stream should consider the time.

Yet, the type and format of information may vary, i.e. VSM presents the lead time and processing time (Figure 1), while MSM, despite following the same rational, presents the VA – Value Added, the NVA – Non-value Added, and the efficiency value along with the total. It is

important to mention that the process step efficiency is also presented in MSM (e.g. Time variable for laser cutting 74%). As depicted in Figure 2, the production time results are the same.

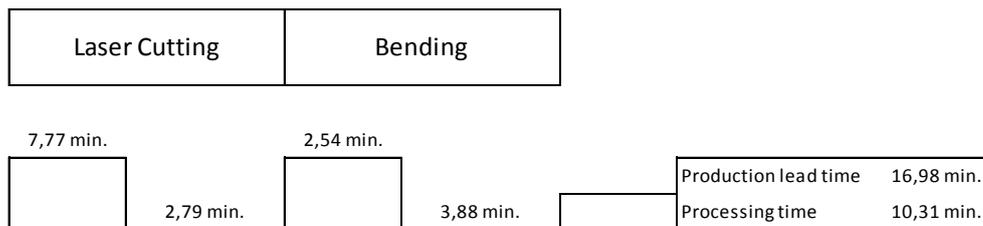


Figure 1 - Metalworking company VSM

However, MSM (Figure 2) presents information for other variables, e.g. energy and raw material consumption. Therefore, in terms of results MSM is able to present the same results as VSM, for the time analysis, and present information about the energy and material efficiency.

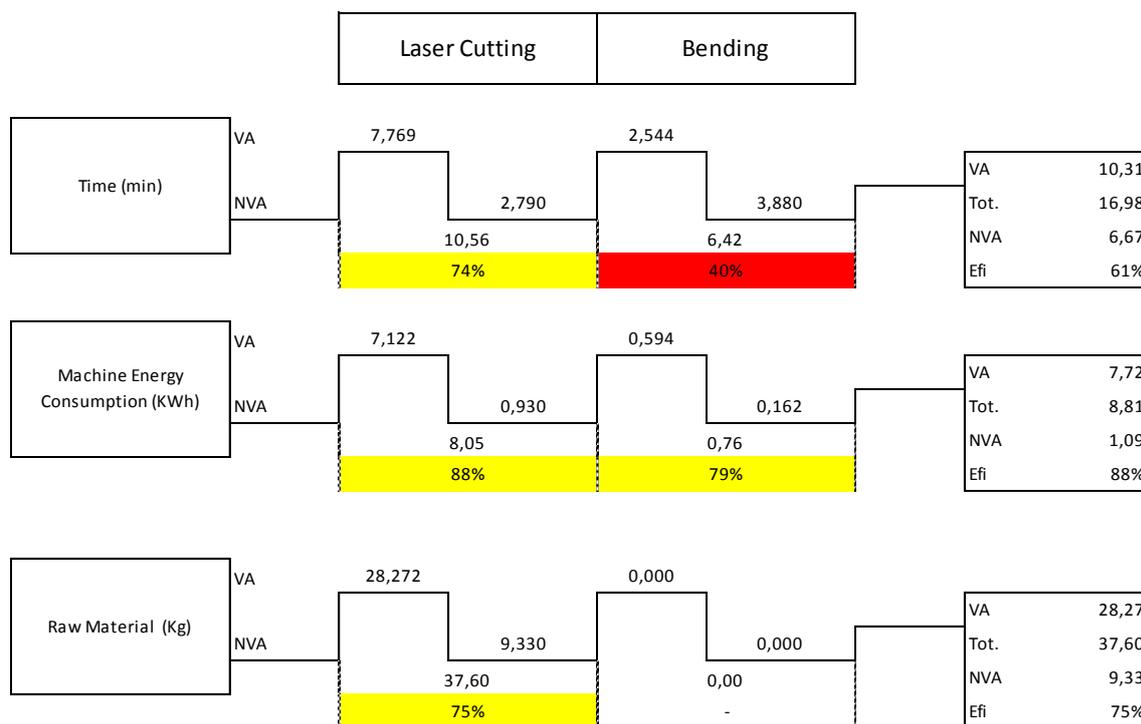


Figure 2 - Metalworking MSM – Efficiency framework

3.3 Results comparison - efficiency framework vs. “conventional” methodologies

SIMAPRO and ecoPROSYS results, show no deviations. In Table 1, for Sodium hydroxide, the result from SIMAPRO is 0.0383 (HH Pt.) and the results for ecoPROSYS is exactly the same (0.0383 HH Pt.). The kg of CO2 eq. for Expandable polystyrene is 2.36 for ecoPROSYS LCA module and SIMAPRO.

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The major differences are related ecoPROSYS' enhanced usability, and capability of modelling the results, in a clear and more user friendly manner. While SIMAPRO, and other available LCA software, are usually limited to the selection of one specific method.

For the MSM time results vs. VSM results, as foreseen, there is no deviation. The production lead time (VSM) is the same as for MSM's time total (16.98 min.). In addition, the processing time

(VSM) is the same as the VA time for the MSM analysis (10.31 min.). Moreover, the as the method of quantification of VA and NVA time for each process step (laser cutting and bending) was the same, these results are the same for both methods. It is important to keep in mind that both methods where applied considering the same data and process steps.

4 Efficiency assessment using the Efficiency Framework

The following sections of this chapter provide and discuss the preliminary results from the assessments of the real industrial case studies using the Efficiency Framework for a company from the chemical sector and a metalworking company. The approach used for this assessment is outlined in "D2.1 - Efficiency Framework concept description" and "D2.2 - Methods for Efficiency Framework for resource and energy efficiency description".

The efficiency assessment for the company from the chemical sector focuses on testing MSM while the preliminary results presented for the metalworking company focuses on testing the Efficiency Framework (ecoPROSYS and MSM) in order to obtain eco-efficiency and efficiency standalone results, as well as the Total Efficiency Index.

The resource and energy efficiency assessment – MSM assessment (assessment will follow the resource and energy efficiency assessment outlined in D2.1 and D2.2), performed for the company from the chemical sector focuses on the identification and quantification of all "value adding" and "non-value adding" actions, as well as, all types of waste and inefficiencies along the production system.

The tests and preliminary results for the metalworking company, consider an eco-efficiency and efficiency assessment. Such results will enable to test and validate the Efficiency Framework as described in "D2.2 - Methods for Efficiency Framework for resource and energy efficiency description". Moreover, this assessment will support on the validation of the new MAESTRI metric - Total Efficiency Index, which in quantitative terms is obtained by multiplying the normalized eco-efficiency and the efficiency assessment results from MSM.

As already mentioned above, all data, and consequently the results, presented in the next chapters are factorized due to confidentiality issues. In addition, the names of the products, process steps and equipment are generic.

4.1 Preliminary results for a company from the chemical sector

4.1.1 Case study characterization

The case study comprises a set of equipment (e.g. tanks and reactors), which are used for the production of chemical products. This process is a typical batch production process and supports the production of more than 100 different products, which are differentiated in terms of recipe. This determines the different process parameters, including its reaction time.

The goal is to establish and define the preliminary results to analyse the energy and resource efficiency of the production of two different example products ("Product 1" and "Product 5") of the company from the chemical sector. Additionally, the efficiency of equipment use (capacity m³) is also addressed in this assessment.

For the efficiency assessment of a company from the chemical sector, two products were considered, named Product 1 and Product 5. It is important to mention that each product has a distinct rout throughout the production system.

The boundaries of the analysis are limited, by the flow of each product:

- The flow of Product 1 is going through: Reactor 1 → Mixing Tank 1 → Mixing Tank 2
- The flow of Product 5 is going through: Reactor 1 → Mixing Tank 1 → Mixing Tank 3

The assessment is based on data, **from some sample batches**, which has been collected for two weeks in 2016. It included data that has been recorded in 2016, for three batches of each product, (i.e. six batches were analysed). The reference value considered, i.e., functional unit was the batch volume. Such functional unit was considered, and not for instance one litre or cubic meter of product, in order to enable to see if there is any correlation between batch size and efficiency of the production system.

Each process step considered for this study and their description are presented in the next table (Table 2).

Table 2 - Process steps considered for the company from the chemical sector

Equipment / Process step	Operational phase	Description
Reactor 1/ Reaction	Reaction	At the reactor, the compounds are always heated additionally there can be a melting step as well reaction temperature of above 200 °C. The reaction is endothermic, meaning that an external source of heat is needed. The solution is maintained inside the reactor, under monitored conditions, and stirred.
	Draining	Transfer of the product from Reactor to Mixing Tank
Mixing Tank 1/ Mixing	Filling	Transfer of the product from Reactor to Mixing Tank
	Mixing	Homogenization and adjustment is done to meet the specification set for the viscosity ratio. Changes of the viscosity also occur during this stage, meaning that it should be considered as a value added operation. The mixing temperature is lower than in reactor. In the mixing tank a final quality control is made before the filtration.
	Agitator off	No mixing is taking place and
	Draining	Transfer the final product from Mixing Tank to storage tank
Mixing Tank 2 (for product 1) / Filling Mixing Tank 3 (for Product 5) / Filling	Filling	A filtration step is included before the filling of the final product for shipment. Tank Lorries, steel drums and intermediate bulk containers are used for final product shipment. The transportation to final customer is sub-contracted.

4.1.2 Identification of the VA and NVA process steps and operational phase

As mentioned the efficiency assessment, using the efficiency framework, focuses on the identification and quantification of all "value adding" and "non-value adding" actions. For this case study, the VA and NVA actions were identified for the process steps and the operational phases as depicted in Figure 3.

In principle, MSM only considers a Process Step as a value adding step of the process, i.e. in the Level 1 – process steps, MSM method only the considers the VA's. For the case study the Filling in mixing tank 2 and 3 is classified as VA action, since during this process step a filtration is done, this adds value to the product (i.e. fiscal changes take place). It is worth mentioning,

that despite the draining and filling, between Reactor 1 and Mixing tank 1, being a single step, both operational phases are considered NVA since the draining adds no value to the product, and it only finishes when the filling is done, i.e. the Reactor 1 will only be free after the draining is done (such considerations foresee that draining and filling take the same for consecutive process steps and are NVA). Such approach was considered in order to enable the assessment efficiency of equipment use. Otherwise, it would not be possible to evaluate and understand if the final filling tank's capacity was being used in an efficient way, i.e. assess capacity efficiency.

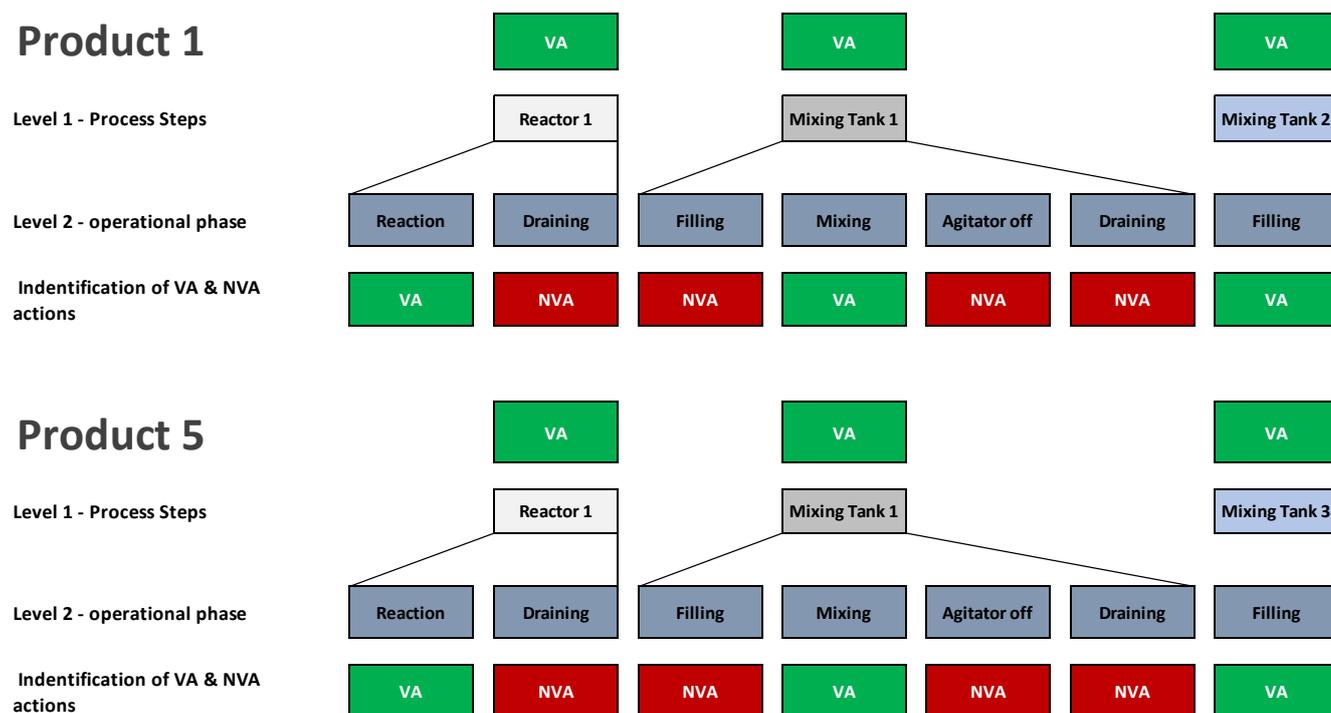


Figure 3 – VA and NVA actions for the company from the chemical sector.

4.1.3 Efficiency assessment using MSM

As mentioned before **six example batches were studied**, in this section we will present the results of the assessment of two example batches, one for each product (Product 1 and Product 5).

The variables assessed for each product are the same. Three resource variables were considered (Time, Energy, Nitrogen), and one operational variable (Equipment capacity).

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For a faster assessment of the efficiency, visual management attributes were added, by relating a very common key of 4 colours (red, orange, yellow, green) in the positive direction of efficiency, from 0% to 100%. All results follow this colour scheme, as presented in Figure 4



Figure 4 – MSM colour code and efficiency results

One of the cornerstones of the methodology involves the systematic non-dimensionalization of the variables that characterize the production system. The efficiency ratios are calculated by the ratio between the portion of the “variable that adds value” (VA) to the product and the “total of the variable that enters the process step”.

The following results refer to an example batch for the production of 37445 litres of Product 1 – Batch 1.

Figure 5 and Figure 6, show the expanded MSM diagram. With such results it is possible to have a better understanding of the efficiency of each process step for the analysed variables. For instance in Figure 5 it is possible to see that only around 18 minutes of mixing tank 1 time add value to the product. In Figure 6, it is also possible to see the total capacity of the equipment and its unused volume. These expanded diagrams are helpful to see the quantities¹; this is helpful for a better understand of the inefficiencies that may take place in the process.

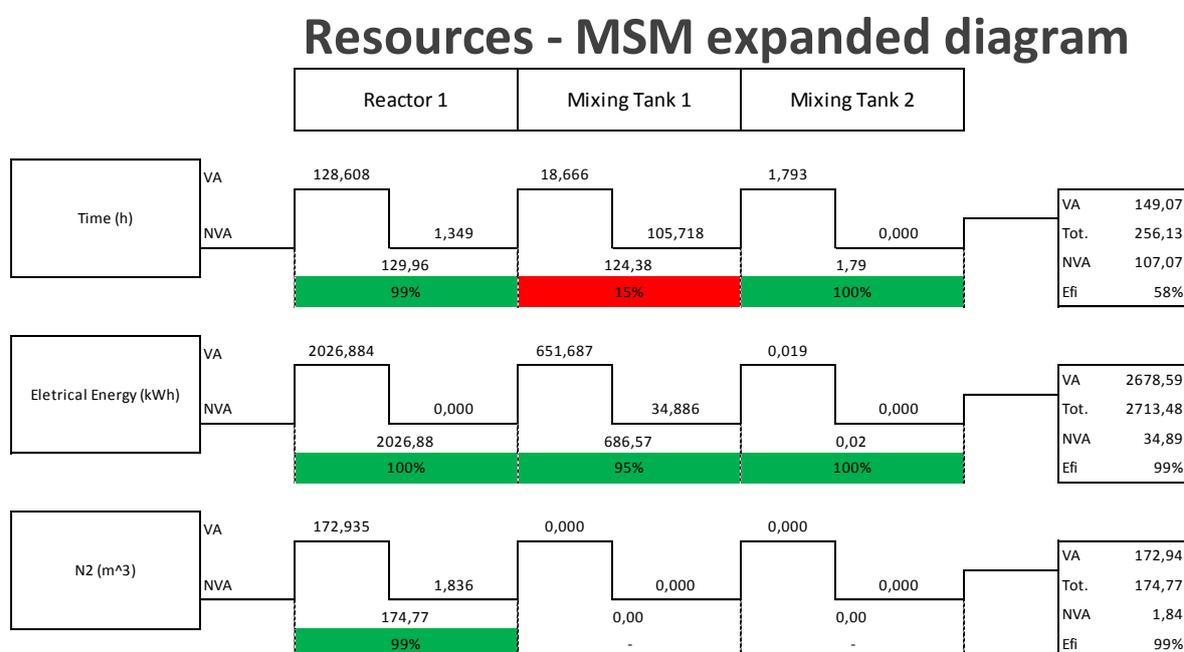


Figure 5 – Resource efficiency for Product 1 example batch - company from the chemical sector.

¹ Despite the factorization of the data and results, due to confidentiality issues, it is important to keep in mind that the metering system for the quantities is not very precise.

Operations - MSM expanded diagram

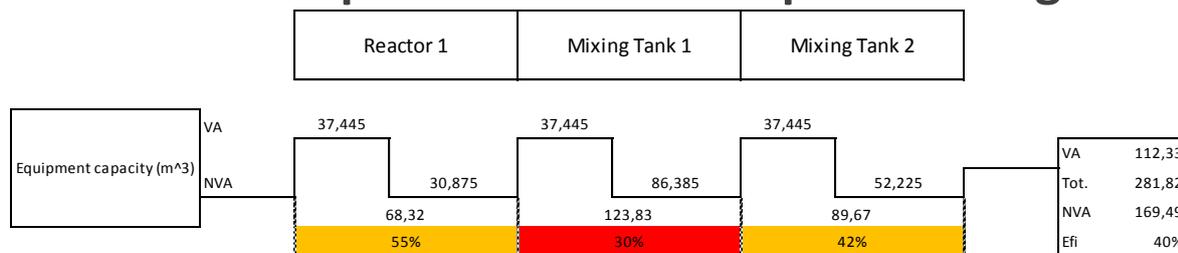


Figure 6 – Operational efficiency for Product 1 example batch - company from the chemical sector

The MSM scorecards presented in Figure 7 and Figure 8, depict, basically, the same information as presented in the Figure 5 and Figure 6. The scorecards do not show the quantities for each variable, but the scorecard are important to show the overall resource and operational efficiency for each process step and for the production process. As presented, the overall resource and operational efficiency for the production process of this example batch of Product 1 is 85% and 42%, respectively, this meaning that 85% of time, energy and nitrogen are used to add value to the product, and that 42% of the capacity of the reactor and mixing tanks are being used. The analysis of these **sample batches**, shows that possibly the capacity efficiency could be improved and that the time product spends in the mixing adding value (15% - long time with agitator off)) should also be looked at.

Finally, the overall efficiency scorecard for the example batch of product 1 (Figure 9), shows that the processes' overall efficiency is 64%, and from a simple analysis, to the samples batches, it is possible to say that this is mainly due to low operational efficiency, namely due to low capacity efficiency – as the reactor is almost half the size of the mixing tank. The mixing tank 1 has an overall efficiency just below 50% (43%). As mentioned above the mixing tank 2 is a VA process step so in terms of resource efficiency, it is 100% but in terms of capacity efficiency it is 42%, which is higher than mixing tank 1 capacity efficiency (30%). **The difference between the size of the reactor and the mixing tanks (technical aspects) is the main reason for such operations overall efficiency results, for this example batch, for instance, if the reactor were used to full capacity efficiency i.e. 100%, the mixing tank 1 and 2 would have a theoretical maximum capacity efficiency of 55% and 76%, respectively. Therefore, the operational efficiency for the mixing tank 1 and 2, are 25% and 34%, respectively, from the theoretical optimum utilization of the capacity.**

Processing unit	Reactor 1	Mixing Tank 1	Mixing Tank 2	
Resource overall efficiency	99%	55%	100%	85%
Time (h)	99%	15%	100%	58%
Electrical Energy (kWh)	100%	95%	100%	99%
N2 (m ³)	99%	-	-	99%

Figure 7 – MSM Resource efficiency Scorecard for Product 1 example batch - company from the chemical sector

Processing unit	Reactor 1	Mixing Tank 1	Mixing Tank 2	
Operations overall efficiency	55%	30%	42%	42%
Equipment capacity (m ³)	55%	30%	42%	40%

Figure 8 - MSM Operational efficiency Scorecard for Product 1 example batch - company from the chemical sector

Processing unit	Reactor 1	Mixing Tank 1	Mixing Tank 2	
Overall efficiency	77%	43%	71%	64%
Resource overall efficiency	99%	55%	100%	85%
Operations overall efficiency	55%	30%	42%	42%

Figure 9 - MSM Overall efficiency Scorecard for Product 1 example batch - company from the chemical sector

The following results refer to an example batch for the production of 60894 litres of Product 5 – Batch 2.

Figure 10 and Figure 11 show the expanded MSM diagram for Product 5 – Batch 2. With such results it is possible, for instance, to see that total mixing and draining time for this example batch of Product 5 (70 minutes) is much lower than the time in mixing tank 1 for product 1 (in Figure 5 124 minutes). Yet, one must keep in mind that these are two different products and for that reason, the total time in mixing tank 1 may be very different. Nonetheless, the NVA time in the mixing tank 1, for this batch of product 5 (1 minute) is much lower than for the Product 1 example batch (105 minutes).

Moreover, in these expanded diagrams, it is possible to see that that the capacity of the equipment - reactor 1, and for mixing tank 1, have the same volume for both products. Yet, the equipment's used capacity is much higher for this Product 5 batch, since the batch volume is much higher (Figure 11). **For this, example batch, if the reactor were used to full capacity (100%) the mixing tank 1 and 3 would have a maximum capacity efficiency of 55% and 53%, respectively.**

Resources - MSM expanded diagram

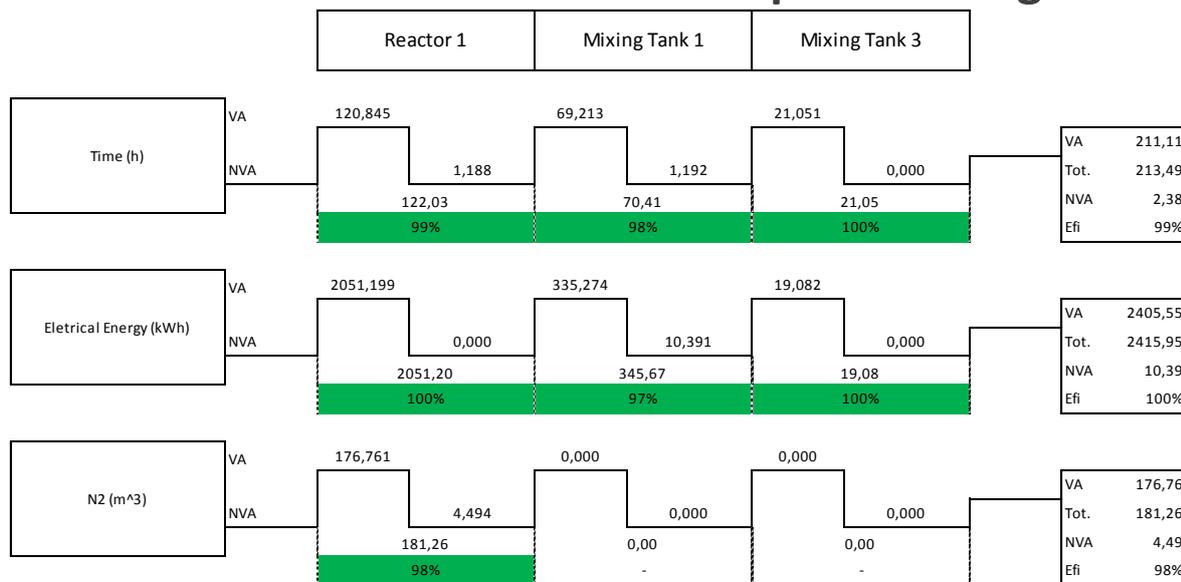


Figure 10 -Resource efficiency for Product 5 example batch - company from the chemical sector

Operations - MSM expanded diagram

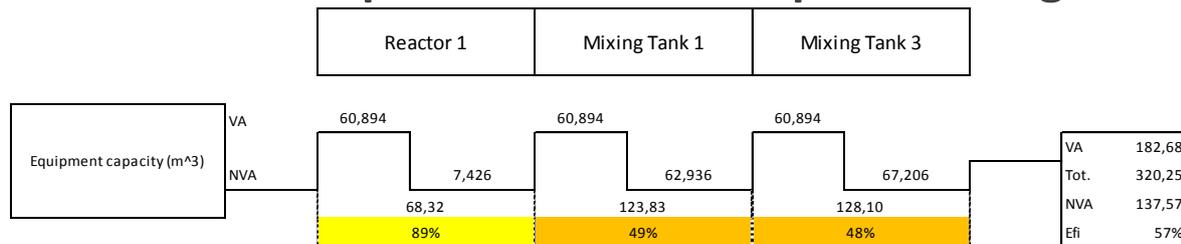


Figure 11 - Operational efficiency for Product 5 example batch - company from the chemical sector.

The MSM scorecards presented in Figure 12 and Figure 13 show that the resource and operational efficiency for the production process of the example batch of Product 5 is 99% and 62%, respectively, this is higher than for the example batch of product 1 (85% and 42%). It is also important to mention that the energy efficiency in mixing tank 1 for this example batch of Product 5 is 98%. **Nonetheless, one must keep in mind that 97% of energy efficiency means that 97% of the energy used in mixing tank 1 for product 5 was used for VA actions of the process step (the same logic applies to the other resource variables).** Yet the major difference for the resource efficiency between Product 1 and Product 5 is related with the time in mixing tank 1.

The capacity efficiency also differs quite a lot between the two example batches. The operational efficiency for the production process for the example batch of Product 1 is 42%, while for Product 5 it is 62%.

The overall efficiency scorecard for the example batch of for product 5 (Figure 14), shows that the processes' overall efficiency for this batch is 80%, this is higher than for product 1 (64%). Bearing in mind a simple analysis, and considering just the two example batches, the analysis shows that, such difference is mainly due to low the capacity efficiency of the mixing tank 1 and the high time product 1 spends in the mixing tank 1 not adding value.

Processing unit	Reactor 1	Mixing Tank 1	Mixing Tank 3	
	☞	☞	☞	
Resource overall efficiency	99%	98%	100%	99%
Time (h)	99%	98%	100%	99%
Electrical Energy (kWh)	100%	97%	100%	100%
N2 (m ³)	98%	-	-	98%

Figure 12 - MSM Resource efficiency Scorecard for Product 5 example batch - company from the chemical sector

Processing unit	Reactor 1	Mixing Tank 1	Mixing Tank 3	
	∞	∞	∞	
Operations overall efficiency	89%	49%	48%	62%
Equipment capacity (m³)	89%	49%	48%	57%

Figure 13 - MSM Operational efficiency Scorecard for Product 5 example batch - company from the chemical sector

Processing unit	Reactor 1	Mixing Tank 1	Mixing Tank 3	
	∞	∞	∞	
Overall efficiency	94%	73%	74%	80%
Resource overall efficiency	99%	98%	100%	99%
Operations overall efficiency	89%	49%	48%	62%

Figure 14 - MSM Overall efficiency Scorecard for Product 5 example batch - company from the chemical sector

As mentioned, the analysis was performed for six sample batches, and the resume results of all six assessments are presented in Figure 15. As expected, and as depicted in the Batch overall MSM scorecard, in this sample of 6 batches the main reason for not so high capacity efficiency seems to be the batch volume, and also related with the reactor's capacity which limits the capacity efficiency of mixing tank 1, 2 and 3, as mixing tanks are larger than the reactor.

Considering the batch volume of the six sample batches, for instance example batch 1, 3 and 6, have the lowest volume, therefore these three example batches have the lowest operations overall efficiency (42%). On the other hand, example batches 2, 4 and 5 have the highest operations overall efficiency (62%) and the highest batch volume, consequently example Batches 2, 4 and 5 have the highest Batch overall efficiency - 80% , 80% and 76% respectively.

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It is worth mentioning that example batches 3 and 4, despite the difference in batch volume, they have the very high batch resource overall efficiency (100% and 99%), meaning that the time and energy used to add value to the product have is very high. With the analysis, of these sample batches it possible to see that, despite the volume produced and the influence the volume has on the run time, the efficiency may not vary if the time and energy are mainly used to add value to the product.

Batch number	1	2	3	4	5	6
Product	1	5	1	5	5	1
Batch Volume (m ³)	37	61	38	61	61	37

Batch Overall efficiency	64%	80%	71%	80%	76%	64%
Batch Resource Overall efficiency	85%	99%	100%	99%	90%	86%
Batch Operations Overall efficiency	42%	62%	42%	62%	62%	42%

Figure 15 – MSM Batch overall Scorecard for six sample batches

4.1.4 Using MSM to assess batch report runtime

Typical runtime information of a batch report is depicted in Figure 16. The production start to end considers the pure reaction time in a reactor and mixing, while batch start to end considers the overall runtime, including pumping the product into the storage tank and possibly additional waiting times. As depicted in Figure 16 only the Run time is considered VA, while Quality Check (QC) and Rework are considered NVA. The filling, as mentioned previously, is NVA.

It is important to mention that without QC to define the needed Rework and the Rework operational phases to correct the batch, the whole batch would go to waste. However, these operational phase are classified NVA (even though the rework may induce chemical changes the product) as rework by definition is NVA.

By analysing the results, of MSM time analysis in Figure 17, it is possible to see that run time has very low efficiency (20%) this is mainly due to QC time. Overall, the process efficiency, for the data presented in Figure 16, considering the production time is around 10%, due to high QC time and rework time, and obviously because from 456 minutes only 45 minutes are VA (for this analysis an negative outlier was selected, in order to depict a worst case scenario). The main improvement should focus obviously on avoiding rework. However, even without rework, a simple analysis enables to conclude that the QC time should be looked into since it is the main contributor for such low efficiency.

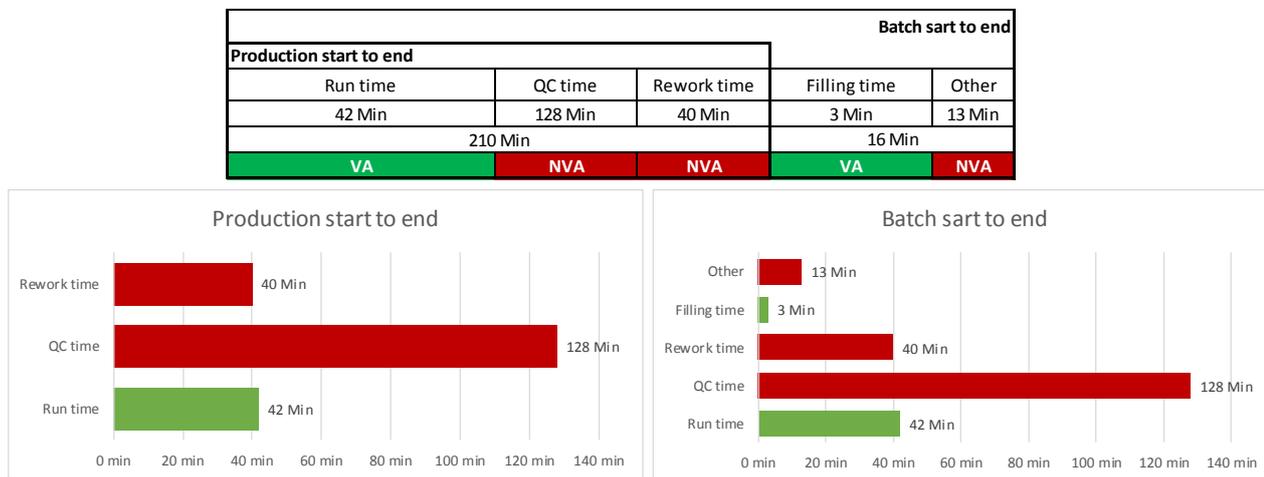


Figure 16 - MSM approach/logic for capturing the NVA activities in a company from the chemical sector



Figure 17 – MSM time analysis for a company from the chemical sector

4.2 Preliminary results for a metalworking company - using the Efficiency Framework to calculate the TEI

4.2.1 Case study characterization

The case study comprises two manufacturing units (Manufacturing Unit 1 – MU1 and Manufacturing Unit 5 – MU5), which support the non-automotive business of the company. These units support, from a manufacturing point of view, three different businesses areas - all of them with a large number of products needing a large number of individual manufactured components.

This line under study takes the raw material through several processes such as laser cutting, ending, welding, polishing, finishing, painting, assembly, packaging and shipping. For the preliminary results for a metalworking company - using the Efficiency Framework, the Laser cutting and bending production process were assessed. Therefore, the goal is to establish and define the preliminary results to analyse the energy and resource efficiency of the production of the two different process steps, the laser and bending, that are necessary.

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For the efficiency assessment of the metalworking company, one product was considered, namely, metal part for a heating device. The boundaries of the analysis are limited, by the flow of product:

- The flow of metal part going through: Laser cutting → Bending

Data was collected in loco during several months. It included data, for production of 19 metal parts for a heating device. The data collection was done by "following" on the shop floor a specific production order. The reference value considered, i.e. functional unit was 1 part. Such functional unit, in order to enable the calculation of TEI as MSM and ecoPROSYS should consider the same data and same functional unit. Besides, by considering the data for one part for a heating device does not influence the analysis and enables to have all values reported to the most elementary unit, in this case the production of one part.

The process steps, considered for this study and their description are presented in the next table (Table 3).

Table 3 - Process steps considered for the metalworking company

Process step	Description
Laser Cutting	Laser cutting machine is used for metal sheets with higher dimensions and/or with thicknesses of 4mm or higher
Bending	The bending process depends mainly on the alloy being processed, the thickness of the part and the fold's angle and shape.

4.2.2 Identification of the VA and NVA process steps and operational phase

The efficiency assessment, using the efficiency framework in order to calculate the Total Efficiency Index, requires identification and quantification of all "value adding" and "non-value adding" actions. For this case study, the VA and NVA actions were identified for the process steps and the operational phases as depicted in Figure 18.

As depicted in Figure 18, only the machining is VA, while the setup and the waiting are classified as NVA in the operational phase. The waiting times include the time the operator is away from the workstation and the non-application of SMED (for example, the operator organizes the cut parts before starting to run the next cutting program). At the process step, level both, laser cutting and bending, are classified as VA, since these process steps consist in a value adding activity – change physically the product.

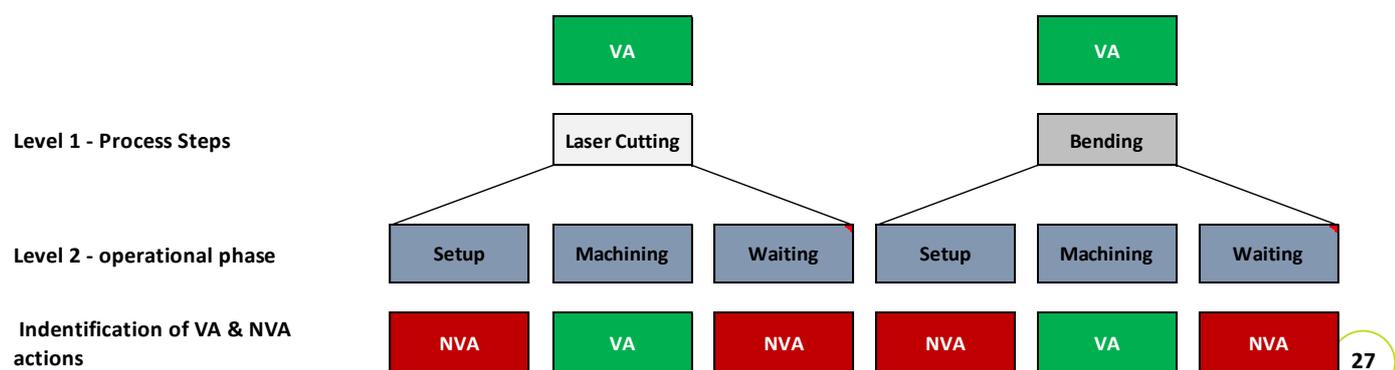


Figure 18 – VA and NVA actions for the metalworking company.

4.2.3 Eco-efficiency assessment using ecoPROSYS

As mentioned above, and according to “D2.2 - Methods for Efficiency Framework for resource and energy efficiency description”, in order to use the Efficiency Framework to calculate the TEI, eco-efficiency ratios have to be calculated. Additionally, it is necessary to quantify the costs or value and the environmental influence for each process step, as well as, the targeted costs or value and environmental influence. Consequently, it is possible to qualify the targeted eco-efficiency ratio for each process step under analysis.

These targeted values arise from the VA portion quantified through MSM, therefore in order to calculate the TEI for each process step, it is necessary to quantify eco-efficiency performance and efficiency performance of each process step.

The preliminary eco-efficiency results using ecoPROSYS, for a metalworking company, are presented in the next table (Table 4). The costs were calculated considering market costs for raw material, energy and consumables. The laser cutting and bending costs, include the all the equipment running costs and the operator costs. The environmental influence for the laser and bending machine also include all aspects related with the machine running. The raw material costs refers to the market costs, and environmental influence is related to the production and use of steel.

The environmental aspects considered for the eco-efficiency assessment refer to the laser and bending machine impacts, to the consumables and energy consumption

The eco-efficiency ratio is calculated by the ratio between costs and environmental influence (as presented in the flowing equation).

$$Eco - Efficiency = \frac{Production\ cost}{Environmental\ Influence}$$

Overall, and considering the eco-efficiency ratios in Table 4 and the eco-efficiency plot (Figure 19) the bending process step has the higher eco-efficiency performance than the laser cutting, as the laser cutting besides higher environmental influence has also higher ruining costs.

Table 4 - Eco-efficiency ratios for the metalworking company using ecoPROSYS

	Costs		EI		Eco-efficiency Ratio
	Total costs		Total EI		Total
Total	32,420	€/part	60,625	Pt/part	0,535
Raw material	15,233	€/part	60,180	Pt/part	0,253
Laser cutting	12,334	€/part	0,204	Pt/part	60,330
Electricity	0,443	€/parts	0,192	Pt/part	2,301
helium	-	-	0,001	Pt/part	-
CO2	-	-	0,000	Pt/part	-
N2	0,012	€/parts	0,004	Pt/part	2,932
Bending	4,356	€/part	0,018	Pt/part	241,340
Electricity	0,042	€/parts	0,018	Pt/part	2,301

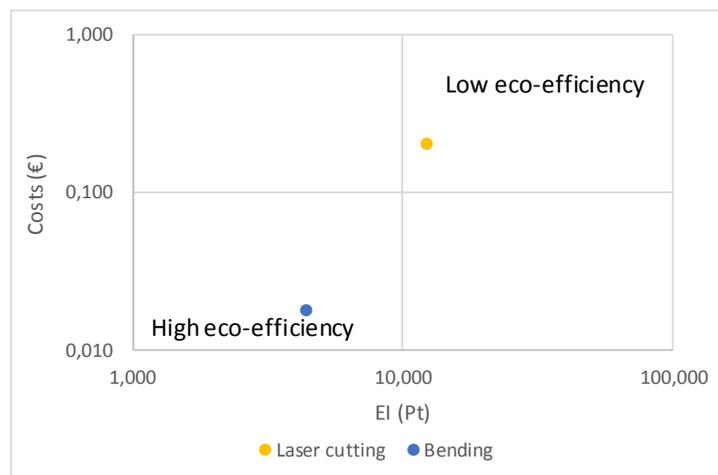


Figure 19 – Eco-efficiency Plot the metalworking company.

4.2.4 Efficiency assessment using MSM

As mentioned, two consecutive process steps were studied. In this section, the preliminary results, are presented, for the efficiency assessment of the Laser cutting and bending process steps.

The resource variables assessed for each process step are the same variables considered for the eco-efficiency assessment. Specifically, for the efficiency assessment three resource variables were considered (Time, Energy, Raw material – steel, consumables), and two operational variables (used area and worker availability). It is important to mention that the **operational variables are not considered for the eco-efficiency preliminary results, as these variables are just used to assess the process' operational efficiency.**

All results follow the colour scheme, as presented in Figure 4, and the efficiency ratios are calculated by the ratio between the portion of the “variable that adds value” (VA) to the product and the “total of the variable that enters the process step”.

Figure 20 and Figure 21 show the expanded MSM diagram with the resource and operational preliminary efficiency results for the metalworking company. It is worth mentioning that the raw material values are only presented in the laser cutting process step, since during the bending the steel part is physically changed but there is no addition or subtraction of material. **As mentioned previously, when looking into energy results one must keep in mind that the VA energy consumption refers to the energy used for “machining” and the NVA energy refers to the energy used for setup and during the waiting.**

The bending process step, despite being faster than the laser cutting, has a higher NVA time.

The used area is an important variable for discrete manufacturing industries, as the metalworking company, since the production process, typically in discrete manufacturing, has designated areas for intermediate stock and for some auxiliary machines. This variable is helpful to better understand if the overall space is being well utilized before taking measures to increase the company' area. Moreover, the used area represents a cost for the company, therefore it is important to use it in an efficient manner. Ultimately, the used area variable may enable one to better understand where is there area available in the company.

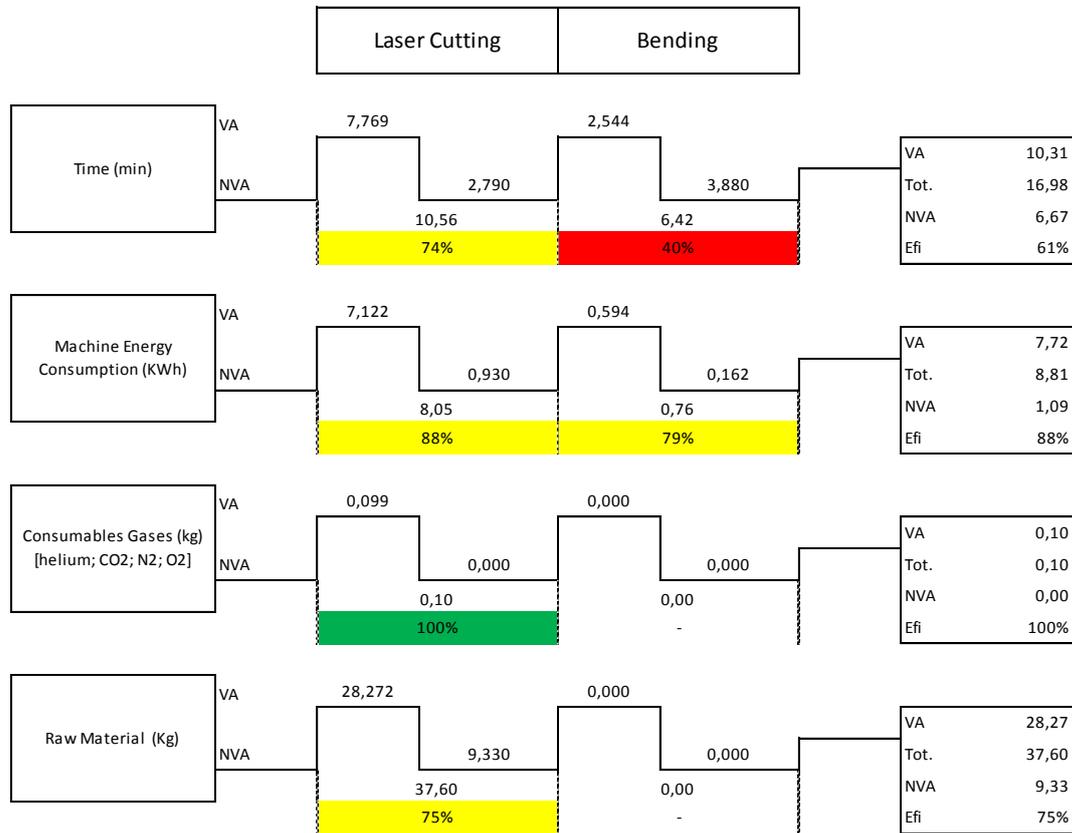


Figure 20 - Resource efficiency of the metalworking company

Operations - MSM expanded diagram

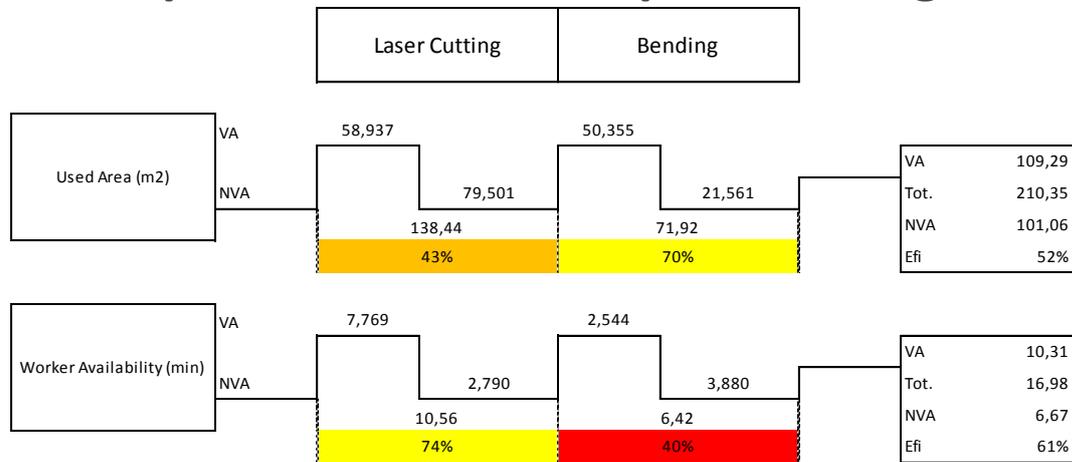


Figure 21 - Operational efficiency of the metalworking company

The MSM scorecards presented in Figure 22 and Figure 23 show that the resource and operational efficiency for the production process is 72% and 56%, respectively.

The bending process step despite having better used area efficiency, has lower resource (59%) and operations (55%) overall efficiency, mainly due to low efficiency for the time variable and consequently for the worker availability.

The overall efficiency scorecard in Figure 24 shows that the processes' overall efficiency is 64%. Considering a simple analysis, it is possible to say that in order to improve the processes' overall efficiency it is necessary to reduce the setup and waiting time in the bending process step.

Processing unit	Laser Cutting	Bending	
	⊗	⊗	
Resource overall efficiency	84%	59%	72%
Time (min)	74%	40%	61%
Machine Energy Consumption (kWh)	88%	79%	88%
Consumables Gases (kg) [helium; CO2; N2; O2]	100%	-	100%
Raw Material (Kg)	75%	-	75%

Figure 22 - MSM Resource efficiency Scorecard of the metalworking company

Processing unit	Laser Cutting	Bending	
	⊗	⊗	
Operations overall efficiency	58%	55%	56%
Used Area (m2)	43%	70%	52%
Worker Availability (min)	74%	40%	61%

Figure 23 - MSM Operational efficiency Scorecard of the metalworking company

Processing unit	Laser Cutting	Bending	
	∞	∞	
Overall efficiency	71%	57%	64%
Resource overall efficiency	84%	59%	72%
Operations overall efficiency	58%	55%	56%

Figure 24 - MSM Overall efficiency Scorecard of the metalworking company

As presented in "D2.1 - Efficiency framework concept", the costs related each process step for each variable is also result from the MSM approach. The result, as presented in Table 5, enables a simple cost analysis which address the value and non-value added costs, namely for raw material, energy and e machine running costs. It is worth mentioning that the costs refer to the costs related with the production of one steel part.

The total cost for the laser cutting includes the raw material cost, and sums up to 28.06 €, of which 7.09 € are used for NVA activities (e.g. setup, waiting, steel scrap). This means that the cost efficiency, for the laser cutting is 75% (Figure 25). Regarding the bending costs, the total is 4.40 €, of which 2.64 € are used for NVA activities (e.g. setup, waiting). In this case, the cost efficiency is 40% (Figure 26).

Such results enable to support the decision making process in terms of prioritization for the implementation of improvement actions for cost reduction. For instance, despite the cost efficiency of the laser cutting being higher than the bending cost efficiency, it is important to notice that for the laser cutting the total NVA (€) is 7.09 € (Table 5), which is more than double than the NVA (€) of the bending process step (2.64 € - Table 5). Therefore, a simple analysis enables to see that the laser cutting should be look into in order to reduce NVA costs, namely by reducing steel scrape and setup and waiting time.

Figure 27 depicts, in a macro manner, such conclusions, as the total NVA (€) of laser cutting is much higher than the total VA (€) and NVA (€) of the bending process step. Overall, the two consecutive process steps under analysis have a cost efficiency of 70% (Figure 27), i.e. 70% of the € used for laser cutting and bending are used to add value to the steel part.

Table 5 – MSM VA and NVA cost assessment of the metalworking company

	Laser Cutting			Bending			Total	
	VA (€)	NVA (€)	Total (€)	VA (€)	NVA (€)	Total (€)	VA (€)	NVA (€)
Time (€) equip. costs	7,88	2,83	10,72	1,31	1,99	3,30	9,19	4,83
Machine Energy Consumption costs (€)	0,39	0,05	0,44	0,03	0,01	0,04	0,42	0,06
Raw Material costs (€)	11,45	3,78	15,23	0,00	0,00	0,00	11,45	3,78
Operator. Cost (€)	1,19	0,43	1,62	0,42	0,64	1,05	1,61	1,06
Total	20,97	7,09	28,06	1,76	2,64	4,40	22,73	9,73

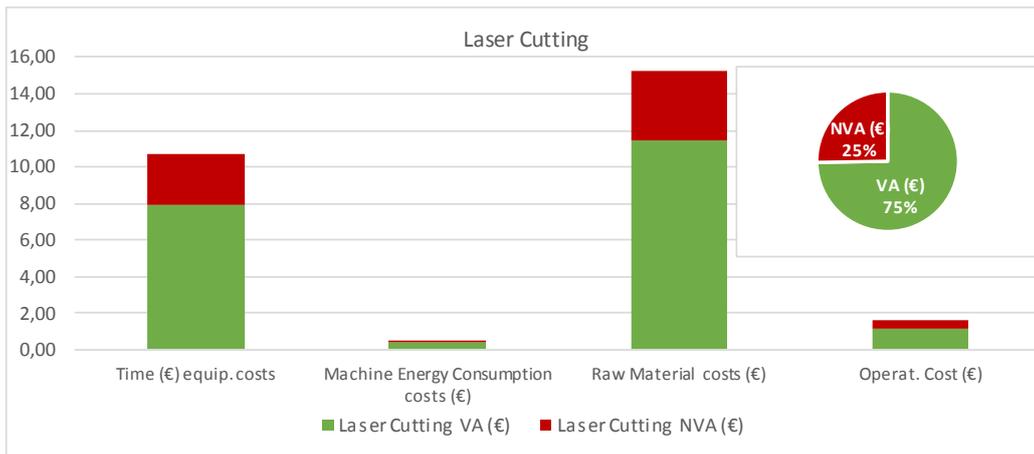


Figure 25 - MSM VA and NVA cost assessment for laser cutting

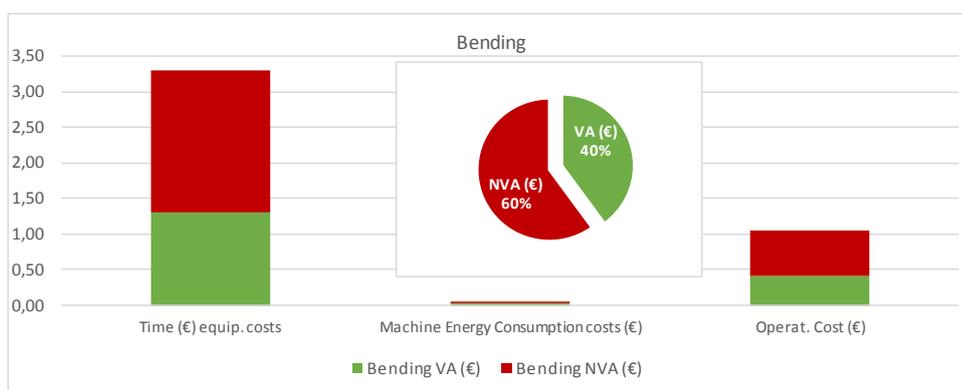


Figure 26 - MSM VA and NVA cost assessment for bending

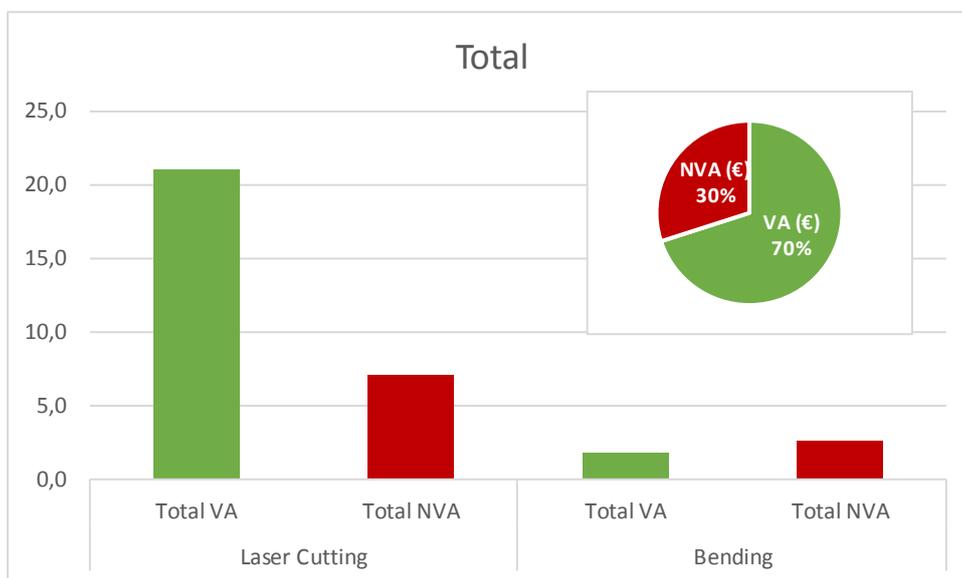


Figure 27 - MSM VA and NVA cost assessment for laser cutting

4.2.5 Calculating the TEI

In order to calculate the Total Efficiency Index – TEI, as outlined in D2.2, besides the eco-efficiency ratios, the efficiency values for each process step, and the VA and NVA costs it is necessary to quantify the VA and NVA environmental influence for each process step. The VA and NVA EI are calculated via ecoPROSYS.

The environmental influence of the VA and NVA actions, along with the costs are presented in Table 6. It is worth mentioning that the costs are the same as the presented in Table 5, but in Table 6 the laser cutting and bending costs comprise “Time (€) equip. costs” and “Operator. Cost (€)”. The Operator costs in MSM analysis is separated from the machine running costs, because it is an operational variable related with operators' availability.

In general, the eco-efficiency results and the EI for the VA and NVA arise from ecoPROSYS, while efficiency results come from MSM - the quantification of the VA and NVA activities, and the related VA costs. With these results, consequently, it is possible to calculate the cost and environmental influence effectiveness in order to obtain the normalization of eco-efficiency.

With the results from Efficiency Framework it is possible to present the Total Efficiency Index diagram (Figure 28). The main outcome provides the ability to evaluate if eco-efficiency performance variation is due to higher or lower environmental influence, or due to higher or lower economic value.

For this particular case, the metalworking company has a cost effectiveness of 75% and 40% for the laser cutting and bending, respectively. The environmental influence effectiveness is 79% for both process steps. These results represent the distance to the targeted effectiveness, which is 100%. Regarding the normalization of eco-efficiency laser cutting is 94% while the bending is 51%. This means that laser cutting' eco-efficiency performance is 6% from the targeted eco-efficiency performance and bending is 49%. One must keep in mind that the target values are the VA portions.

The product between efficiency values and the normalized eco-efficiency arises as the TEI for each process step. The laser cutting has a much higher TEI (67%) than the bending (29%). It is worth mentioning that the low TEI of the bending is mainly due to low cost effectiveness that influences, in a negative way, the normalized eco-efficiency, which is related to the low time and worker availability efficiency. Therefore, it is possible to state that the bending process step should be looked into, in order to improve the TEI and consequently the overall TEI, which for the production system is 48% (average value of the TEI for the Laser cutting and bending).

In general, the TEI diagram (Figure 28) is very helpful for the decision support process, yet this diagram should always be complemented with the TEI distribution plot (Figure 29). Since, in practice, this results from the distribution variance of TEI results that occur on two major axes: the efficiency and eco-efficiency. This distribution is presented in a graphical way to distinguish the four quadrants, where each quadrant characterises the following:

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- Quadrant I - The production system generates good economic value considering the environmental impacts caused by its activities and high operations efficiency. Then, considering the current technological settings, it tends to have a lower improvement potential.

- Quadrant II - The acceptable eco-efficiency performance is likely to be led by low environmental impacts related to the production system activities. Improvement actions to increase the economic value generation are advisable, namely by improving process efficiency.
- Quadrant III - The production system presents low performance, both low operations efficiency and eco-efficiency. The implementation of improvement actions is extremely recommended.
- Quadrant IV - Despite presenting good efficiency, the production system is not generating the expected value or high environmental impacts. Technological and procedural changes are recommended to decrease environmental impacts.

The results depict that Laser cutting is in Quadrant I - high eco-efficiency performance and relatively good efficiency (around 70%). Which means that the process step generates good economic value considering the environmental impacts caused by its activities, yet efficiency preface has room for improvements. Regarding the bending, this process step is very close to Quadrant IV - medium eco-efficiency and efficiency (around 50%). This means that the bending process step is not generating the expected value and for the relatively high environmental impacts. Procedural changes are recommended to increase efficiency performance, as in reduction of setup and wasting time.

Table 6 – VA and NVA eco-efficiency ratios for the metalworking company using the Efficiency Framework (EI of the bending only considers energy consumption due to the lack of a data set for the EI of bending)

	Costs						EI						Eco-efficiency Ratio		
	VA		NVA		Total costs		VA		NVA		Total EI		VA	NVA	Total
Total	22,690	€/part	9,731	€/part	32,420	€/part	48,186	Pt/part	12,436	Pt/part	60,625	Pt/part	0,471	0,782	0,535
Raw material	11,453	€/part	3,780	€/part	15,233	€/part	47,794	Pt/part	12,384	Pt/part	60,180	Pt/part	0,240	0,305	0,253
Laser cutting	9,074	€/part	3,259	€/part	12,334	€/part	0,182	Pt/part	0,022	Pt/part	0,204	Pt/part	49,803	146,611	60,330
Electricity	0,392	€/parts	0,051	€/parts	0,443	€/parts	0,170	Pt/part	0,022	Pt/part	0,192	Pt/part	2,301	2,302	2,301
helium	-	-	-	-	-	-	0,001	Pt/part	-	-	0,001	Pt/part	-	-	-
CO2	-	-	-	-	-	-	0,000	Pt/part	-	-	0,000	Pt/part	-	-	-
N2	0,012	€/parts	-	-	0,012	€/parts	0,004	Pt/part	-	-	0,004	Pt/part	2,932	-	2,932
O2	0,000	€/parts	-	-	0,000	€/parts	0,007	Pt/part	-	-	0,007	Pt/part	0,003	-	0,003
Bending	1,726	€/part	2,632	€/part	4,356	€/part	0,014	Pt/part	0,004	Pt/part	0,018	Pt/part	121,658	681,154	241,340
Electricity	0,033	€/parts	0,009	€/parts	0,042	€/parts	0,014	Pt/part	0,004	Pt/part	0,018	Pt/part	2,301	2,301	2,301

	Laser Cutting	Bending	
Total efficiency index	67%	29%	48%
Real cost (€)	28,02 €	4,40 €	32,42 €
Target cost (€)	20,93 €	1,76 €	22,69 €
Cost effectiveness (%)	75%	40%	70%
Real environmental influence (Pt)	60,59 Pt	0,0361 Pt	60,63 Pt
Target environmental influence (Pt)	48,16 Pt	0,0284 Pt	48,19 Pt
Environmental Influence effectiveness (%)	79%	79%	79%
Real eco-efficiency	0,462	121,821	122,28
Target eco-efficiency	0,435	61,980	62,41
Normalised Eco-Efficiency (%)	94%	51%	51%
Efficiency (%)	71%	57%	64%

Figure 28 - Total Efficiency Index diagram for the metalworking company using the Efficiency Framework

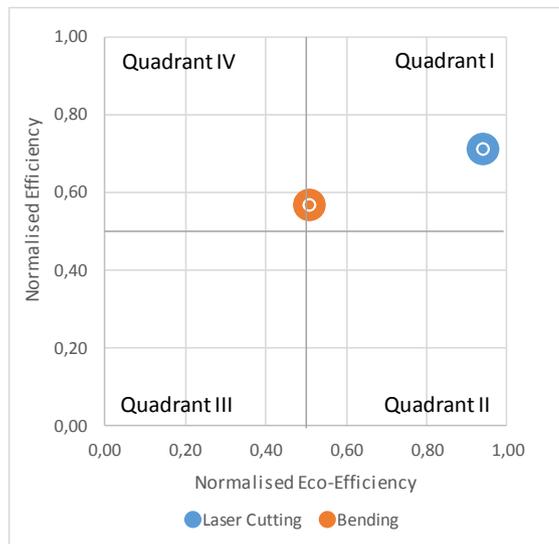


Figure 29 – TEI distribution plot for the metalworking company using the Efficiency Framework

5 Final remarks

The Efficiency Framework stand-alone results for eco-efficiency and efficiency performance, were tested and validated via comparison with “conventional” tools and methods. ecoPROSYS' LCA results when compared with SIMAPRO results presented no deviations, this validating the main module of ecoPROSYS. MSM time results were compared with Value Stream Mapping results, and no deviations were found. Major differences are related with the type and amount of results, i.e. MSM presents results for other variables besides time (energy, raw material, etc.) and with an original form, besides it simplifies part of the VSM methodology, for instance not considering the information flows and actions.

A real industrial case using MSM from the Efficiency Framework for a company from the chemical sector was done. MSM's suitability and adequacy was tested for process industry case study. This validation enabled to concluded that the capacity efficiency is a quite important indicator to assess process industries performance, namely the companies that have batch production processes. Though, the difference between the size of the reactors and the mixing tanks (technical aspects) should be considered, since the capacity of an upstream equipment mas influence the capacity efficiency of a downstream equipment

Overall batch efficiency, i.e. comparison of six batches, was performed. Such analysis was important to have a general understanding of the efficiency for different products. Additionally, such analysis enables to understand the influence the batch volume has on the efficiency, for this industrial case, it was possible to see that batch volume influences the operational efficiency, capacity efficiency.

Moreover, MSM was tested to assess batch report runtime, despite the simple analysis, this is quite suitable for process industries.

The preliminary results for the metalworking company encompass the Total Efficiency Index. This analysis enabled to test and validate the integration of ecoPROSYS and MSM, as it was necessary to calculate the efficiency and eco-efficiency performance. For these results is was possible to foresee, considering simple analysis, some possible improvement actions and the strategy in order to set priorities.

A MSM cost analysis was performed in order to quantify the VA and NVA actions, these results were important to understand how and where to reduce costs. The same quantification was performed for the environmental influence using ecoPROSYS. These results enabled the calculation of the targeted costs and environmental influence, which consequently enabled to define cost and environmental effectiveness and then the normalised eco-efficiency.

Ultimately the TEI was calculated and a TEI diagram was presented in order to help the decision support process, the results from the distribution variance of TEI are presented on two major axes: the efficiency and eco-efficiency. Consequently, it is possible to define a generic improvement approach according to the quadrant.

In conclusion the assessment of the MAESTRI case studies enabled to validate the Efficiency Framework and present preliminary results for real industrial case studies.

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