Total Resource and Energy Efficiency
Management System for Process Industries

Deliverable 2.2

Methods for Efficiency Framework for resource and energy efficiency description

Date: 30/08/2016

WP2 Efficiency Framework

T2.2 Integration of the eco-efficiency and efficiency methodologies and tools

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Sustainable Process Industry through Resource and Energy Efficiency

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List of Acronyms

ecoPROSYS© - Eco-Efficiency Integrated Methodology for Production Systems

EE – Eco-Efficiency

EI – Environmental Influence

EPE – Environmental Performance Assessment

EOP – Eco Orbit View

GVA – Gross Value Added

IS – Industrial Symbiosis

ISO – International Organization for Standardization

KEPI – Key Environmental Performance Indicator

KPI - Key Performance Indicator

LCA – Life Cycle Assessment

LCC – Life Cycle Cost

LCT – Life Cycle Thinking

MSM© - Multi-Layer Stream Mapping methology

NVA – Non-Value Added

OECD – Organisation for Economic Co-operation and Development

PBCM – Process Based Cost Model

PBM – Process Based Model

PE – Process Efficiency

PMS – Performance Management System

Pt – environmental impact points

TEI – Total Efficiency Index

UP – Unit Process

VA – Value Added

VSM – Value Stream Mapping

WBCSD – World Business Council for Sustainable Development

WIP – Work-in-progress

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1 Executive Summary

The MAESTRI project aims to advance the sustainability of European manufacturing and process industries. This will be done by providing a Management System in the form of a flexible and scalable platform, aiming to guide and simplify the implementation of the Total Efficiency Framework in organizations, which encompasses: Efficiency Framework, Management Systems and Industrial Symbiosis, supported by an Internet-of-Things (IoT) platform as base layer.

The overall aim of the Efficiency Framework is to encourage a culture of continuous improvement within manufacturing and process industries. It supports informed decision-making processes and strategies for continuous performance improvement. Furthermore, the proposed framework accounts simultaneously for the environmental and economic performance, helping to define priorities and estimate impacts.

This document presents an innovative Efficiency Framework which is materialized through the integration of concepts and results provided by 1) the eco-efficiency methodology ecoPROSYS© – an "Integrated methodology which allows the evaluation and assessment of eco-efficiency performance" and 2) the efficiency assessment methodology MSM© – Multi-Layer Stream Mapping - a lean based method. This Efficiency Framework aims to facilitate the overall efficiency performance assessment of complex systems (such as for production systems) by an integrated multi-dimensional analysis.

In addition, the interactions between Eco Orbit View (provided by WP3 – Management System) and the Efficiency Framework are also presented in this document, along with the interaction between WP4 - Industrial Symbiosis and the Efficiency Framework. Initial definition of interrelation between Total Efficiency Framework and MAESTRI IoT platform is described in D5.1 – Initial MAESTRI Platform Architecture Design and Specification.

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2 Introduction

The main goal of WP2 is to develop the Efficiency Framework, which encompasses several modules: i) eco-efficiency (environmental influence and economic performance); ii) resource and energy efficiency; and iii) overall efficiency assessment.

In addition, WP2 is connected to WP3 and WP4, since its developments and integrated framework are aligned with the developments of the Management System and the Industrial Symbioses approach, respectively. For these reason, it combines inputs for the integration of different aspects including eco-efficiency as well as economic and environmental performance, operational efficiency, value and waste identification, strategy deployment for continuous improvement and change management.

After the definition of Efficiency Framework concept (as provided in D2.1[1]), the main goal of this document is to clearly define and characterize a new approach for the integration of the two existing methodologies ecoPROSYS© and MSM©, in such a manner that enables the Efficiency Framework to be used in an integrated way to assess eco-efficiency and efficiency performance, as well as to assess the overall production system efficiency. This integrated framework should empower a flexible and straightforward analysis facilitating implementation and use, and enable decision support analysis in different processes in industries of different types and sizes. Its originality is founded not only on the integration of results of the two original methodologies (ecoPROSYS© and MSM©), but also on the creation of a concurrent assessment of eco-efficiency (including LCA and LCC aspects) and operational efficiency (with foundations on Lean Manufacturing value/waste assessment) with focus on the creation of practical and user-friendly analysis and tools. This concurrent assessment converges into a compromise between cost effectiveness and cost efficiency which can be used for informed decision making.

Another relevant topic is the interconnection of Eco-efficiency Principles with Lean Principles, to foresee synergic aspects and the definition of potential improvement areas that suits simultaneously eco-efficiency (economic and environment) and Lean Principles (value and waste identification). Improvement of synergic aspects implies positive results simultaneously for eco-efficiency and operational efficiency (and the respectively cost and environmental influence reductions).

The approach applied for the integration between ecoPROSYS© and MSM© is based primarily on the combination of results from both ecoPROSYS© and MSM©, not on the fusion of the two methodologies.

Moreover, this work also defines the strategy to integrate the Efficiency Framework with the Eco Orbit View [2] (interconnection with WP3) and the Industrial Symbiosis aspects (interconnection with WP4). The connection between Eco Orbit View and MSM© is one of the links for integrating Eco Orbit View with the Efficiency Framework. The other link consists in integrating eco-efficiency principles with Management System's lean perspective. The

[1] Deliverable 2.1 on Efficiency Framework concept description

[2] a description of Eco Orbit View is available at Deliverable 3.1 on Analysis of organizational challenges and barriers.

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interaction between the Efficiency Framework and Industrial Symbiosis is attained by using the MSM© results for "How to see waste" and the ecoPROSYS© results for "How to characterise waste".

These developments address challenges that are important nowadays in industry management (EC 2014), and in particular in the process industries, that face not only pressure for operational cost reductions, but at the same time severe regulations towards environment protection.

Considering the developments resulting from the implementation of task 2.2, the next chapters present the approach to be used on the integration of ecoPROSYS© and MSM©, considering their interaction with both Eco Orbit View and Industrial Symbiosis concepts.

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3 Integration of the ecoPROSYS© and MSM© approaches

The outline of the integration of ecoPROSYS© and MSM© concerns the exchange of information between efficiency and eco-efficiency assessments. In fact, such exchange of information is the main focus of the integration of the two methods in order to support the decision making process, considering efficiency, environmental and economic performance as whole and not as isolated domains.

However, the integration is a complex task considering the two different concepts behind these tools. In practical terms this represents the possibility of making an efficiency assessment based on the eco-efficiency principles and efficiency performance, as well as, to assure that simulations for eco-efficiency provide also information and improvements of efficiency performance.

Next sections of this chapter present the outline, as well as the main outcomes and challenges related to the practical implementation of ecoPROSYS©, as an eco-efficiency assessment tool, and MSM©, as an efficiency assessment tool.

3.1 Integration and combination of the eco-efficiency and efficiency methodologies and tools

The integration of ecoPROSYS© and MSM© methodologies and tools corresponds to the central objective of the Efficiency Framework.

The *Eco-Efficiency Integrated Methodology for Production Systems* (ecoPROSYS©) approach relies on the use of a systematized and organized set of indicators which are easy to understand and analyse. The goal of having such a set of indicators is to promote continuous improvement as well as an efficient use of resources and energy. The goal is to assess eco-efficiency performance in order to support decision-making and enable the maximization of product / service value creation and minimization of environmental burdens. The Multi-layer Stream Mapping (MSM©) methodology focuses on the overall efficiency and performance assessment of production systems. It takes into account the base design elements and foundations of VSM (Value Stream Mapping), in order to identify and quantify all "value adding – VA " and "non-value adding - NVA" activities as well as all types of waste and inefficiencies along the production system. There is a great similarity between MSM and VSM, as both approaches identify and quantify, at each stage of the production system, unit process, of "what adds value" and "what does not add value" to a product or service. The basic principle of the MSM© methodology relates to Lean Principles, (i.e. a clear definition of value and waste). These methodologies are described in detail in Deliverable 2.1 - Efficiency Framework concept description.

The approach followed to integrate ecoPROSYS© and MSM© is primarily through the combination of the eco-efficiency and efficiency results as opposed to a fusion of results. Such approach enables to obtain efficiency and eco-efficiency *stand-alone* results to support decisions, in addition to the new integrated results, namely the:

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- *Total Efficiency Index*: It is a new metric of MAESTRI which is obtained by integrating results from ecoPROSYS© and MSM©, i.e. combine eco-efficiency KPIs with MSM© efficiency metrics and architecture;
- Environmental and value performance: These results are based on real and target figures;
- Normalized eco-efficiency: combining results from real and target eco-efficiency ratios for each process step of a production system;
- *Effectiveness of accomplishment for each eco-efficiency principle*: It is obtained by the interaction between ecoPROSYS© and MSM©'s efficiency assessment method;
- Environmental influence and costs of the VA and NVA activities: These are obtained by integrating results from ecoPROSYS© and MSM©.

3.1.1 How results are combined for integration

As mentioned before, the outcomes of the Efficiency Framework will enable to simultaneously assess eco-efficiency and efficiency performance by using the direct results from ecoPROSYS© and MSM©, respectively. These results, in addition to supporting a more complete and informed decision-making process regarding sustainable development play also an important role when it comes to reporting. Eco-efficiency reports and environmental performance reporting both inter- and intra-company present the efficiency and eco-efficiency assessment results through scorecards/dashboards within the Efficiency Framework.

Besides the *stand-alone* results, from both ecoPROSYS© and MSM©, targets can be defined considering the eco-efficiency ratios resulting directly from environmental influence and economic value arising from the VA efficiency assessment of the MSM© approach. One major consideration for presenting the ratios and the targets is that these should always be *self-contained*. This means that the results for a certain unit process (i.e. the smallest element considered in the production system for which input and output data are quantified) are only dependent on the variances that occur in that unit process. Therefore, major efficiency, environmental or value variations occurring in a certain unit processes, will not affect positively nor negatively the results of other unit processes, thus ensuring a robust decision making process.

The combination of the efficiency and eco-efficiency results will enable to assess the effectiveness of the eco-efficiency performance improvement. This will be done by monitoring deviations between the real eco-efficiency (real economic value over real environmental influence) and targeted eco-efficiency (target economic value over target environmental influence). Moreover, the goal is to evaluate if eco-efficiency performance variation is due to higher or lower environmental influence, or due to higher or lower economic value.

The Efficiency Framework results and scorecards should show different information according to the profile (e.g. manager, director, operator, team leader, etc.), and should enable the unfolding/breakdown of the scorecards through the organisational or functional hierarchy of the company. This means that logical link should be implemented in order to make the results available along production system and for the different functional levels of the company. Therefore, as presented in figure 1, this links should be implemented from raw data (shop floor data, e.g. energy consumption from a specific machine), to unit process, sectors, all the

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way to Plant, Company or Group Level presenting the global aggregated data (overall business aspects).

3.2 The Total Efficiency Index

Regarding the new outcomes from the Efficiency Framework, the new MAESTRI metric called **Total Efficiency Index** (TEI) deserves special attention**.** This new index is calculated for each unit process of the production system under assessment but can be successively aggregated for the complete production process of a given product (hierarchical pyramidal integration of the results from each level) – see Figure 1. In quantitative terms, TEI is obtained by multiplying the normalized eco-efficiency and the efficiency assessment results from MSM© (see equation 1). The normalized eco-efficiency ratio represents, in percentage, the relation between real and targeted eco-efficiency performance (see equation 2) and is calculated dividing the real eco-efficiency ratio (see equation 3) by the targeted eco-efficiency ratio (see equation 4).

$$\text{Total Efficiency Index (\%)} = \text{Normalized eco-efficiency} \times \text{Process efficiency} \qquad \text{Equation 1}$$

$$\text{Normalized eco-efficiency (\%)} = \frac{\text{Real eco-efficiency ratio}}{\text{Target eco-efficiency ratio}} \qquad \text{Equation 2}$$

$$\text{Real eco-efficiency ratio (\%)} = \frac{\text{Real value}^{3}\ (€)}{\text{Real environmental influence (Pt)}} \qquad \text{Equation 3}$$

$$\text{Target eco-efficiency ratio (\%)} = \frac{\text{Target value (€)}^{4}}{\text{Target environmental influence (Pt)}^{5}} \qquad \text{Equation 4}$$

$$\text{Value effectiveness (\%)} = \frac{\text{Real value (€)}}{\text{Target Value (€)}} \qquad \text{Equation 5}$$

$$\text{Environmental influence effectiveness (\%)} = \frac{\text{Real environmental influence(Pt)}}{\text{Target environmental influence(Pt)}} \qquad \text{Equation 6}$$

The logic behind this index is to combine two fundamental efficiency aspects, namely **eco-efficiency**, which considers the ecology and economy (with the ecoPROSYS© methodology), and **operational efficiency**, which considers the NVA and VA activities in respect to the Lean Principles application (by MSM© methodology).

Figure 2 presents the calculus diagram for the Total Efficiency Index, integrating results from ecoPROSYS© and MSM© and also applying the algorithm of MSM© for the integration and visual representation of the results (scorecard).

[3] Value may not refer only to € but also to a functional value, for instance durability, lumens, etc.
[4] Target value is the same as the VA portion quantified in the efficiency assessment
[5] Target environmental (Pt) influence is the same as the VA portion quantified in the efficiency assessment

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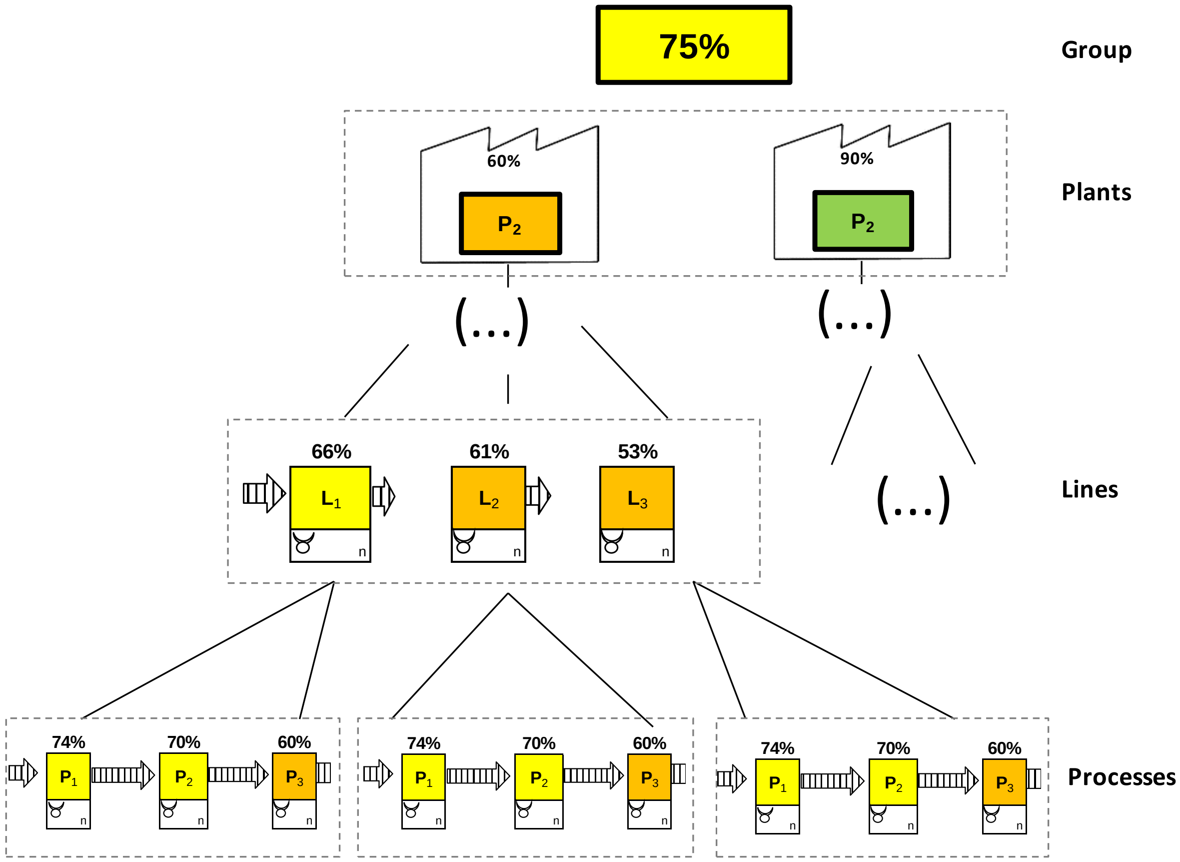

Figure 1 – Hierarchical pyramidal integration of efficiency results for a given product and process sequence (conceptual example from the MSM© framework analysis).

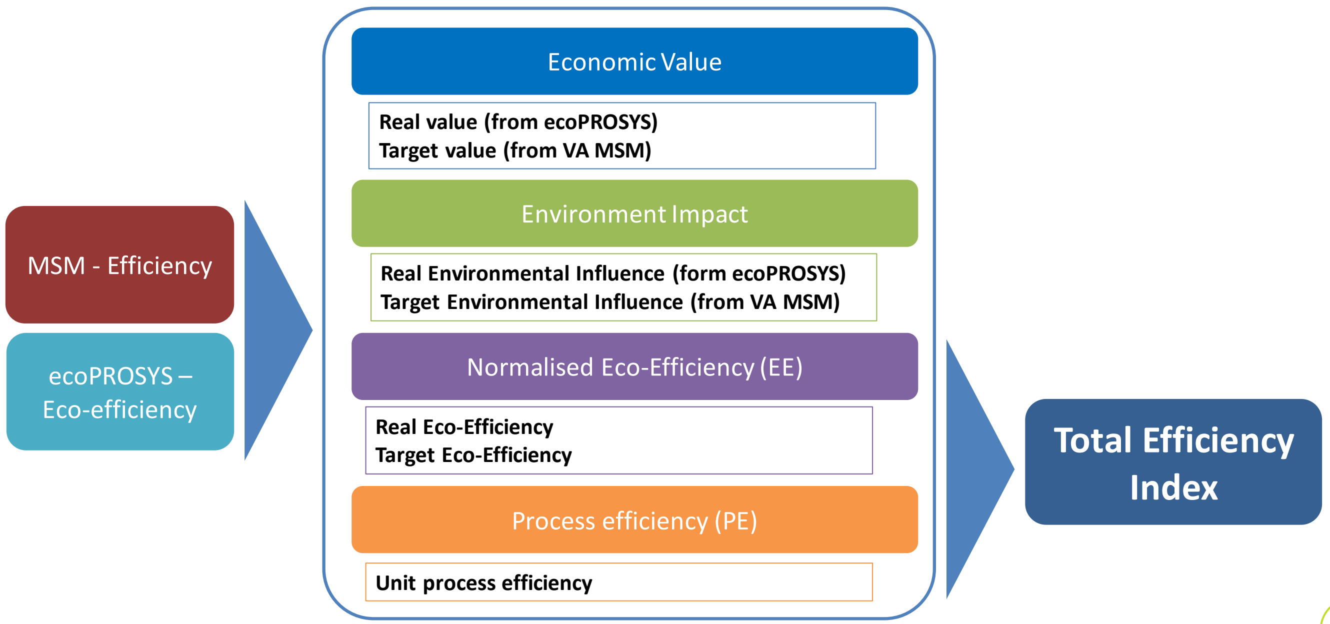

Figure 2 – Total Efficiency Index diagram calculus structure, integrating results from MSM© and ecoPROSYS©.

3.3 Efficiency Analysis

The outcomes from MSM© are combined and integrated in the analysis as direct results (unit efficiency results in %), where the VA helps to set the maximum reduction and the NVA helps to identify priorities to reduce NVA.

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The target setting is defined as a result from MSM©'s VA activities. This figure is considered since the goal is to eliminate/reduce the NVA activities, being the VA the best value (attainable). Yet, the targets can also be defined via an internal set point, or even by a sectorial set-point, as benchmarking amount for a given industrial sector. When using targets based on sector benchmark, this assessment should be performed preferable as "off-line" analysis and could be used for companies to position themselves, always keeping in mind that benchmark just provides a sectorial reference, and is not company specific. Nevertheless, depending on the company's operations and goal setting strategy, the direct benchmark reference targets can be applied if it does not affect the collaborators' motivation (for the case that company's results are seen as poor at that stage). Regarding the technological aspect, the targets should be set for the existing technology in operation at the company. For the cases of technology shift the targets must be updated. In terms of the management strategy, an off-line analysis with benchmark targets can be relevant to measure the company's competitiveness in respect to the state-of-art technology available. All in all, the targets should consider the optimal product or service value (€, years, lumens,…) and optimal environmental influence (Pt or Eco points), e.g. the optimal amount of material consumed. Figure 3 presents the input results from the MSM© methodology.

From the integration point of view, the MSM© results are also used in order to distinguish all VA and NVA activities, enabling ecoPROSYS© modules, namely the LCA and PBCM (process-based cost models), to assess the VA and NVA for environmental influence and costs. For instance, in order to define the targets for eco-efficiency, the MSM© approach is used considering the added value (e.g. (a) 5kg of steel add value, therefore the target for the impact and monetary value should consider 5kg of steel; (b) 1 hour of machining adds value, therefore the target for the impact and monetary value should consider 1 hour of machining).

Besides these results being used for setting targets and consequently target eco-efficiency ratio for the normalization of the eco-efficiency performance, they are also used to quantify the avoidable environmental impacts and costs.

One important remark is that the MSM© approach is founded on the principle that "more is better" i.e. closer to 100% means higher performance. Contrarily, when analysing the integrated results, one must keep in mind that, for eco-efficiency, higher environmental influence (Pt) and costs (€) are worse, but higher added value (e.g. GVA €) and lower impact points are better. Thus, the KPI formula must be well understood by the user, nevertheless, the big objective is to improve the figure for eco-efficiency (then "more is better" and it is aligned with the MSM© principle).

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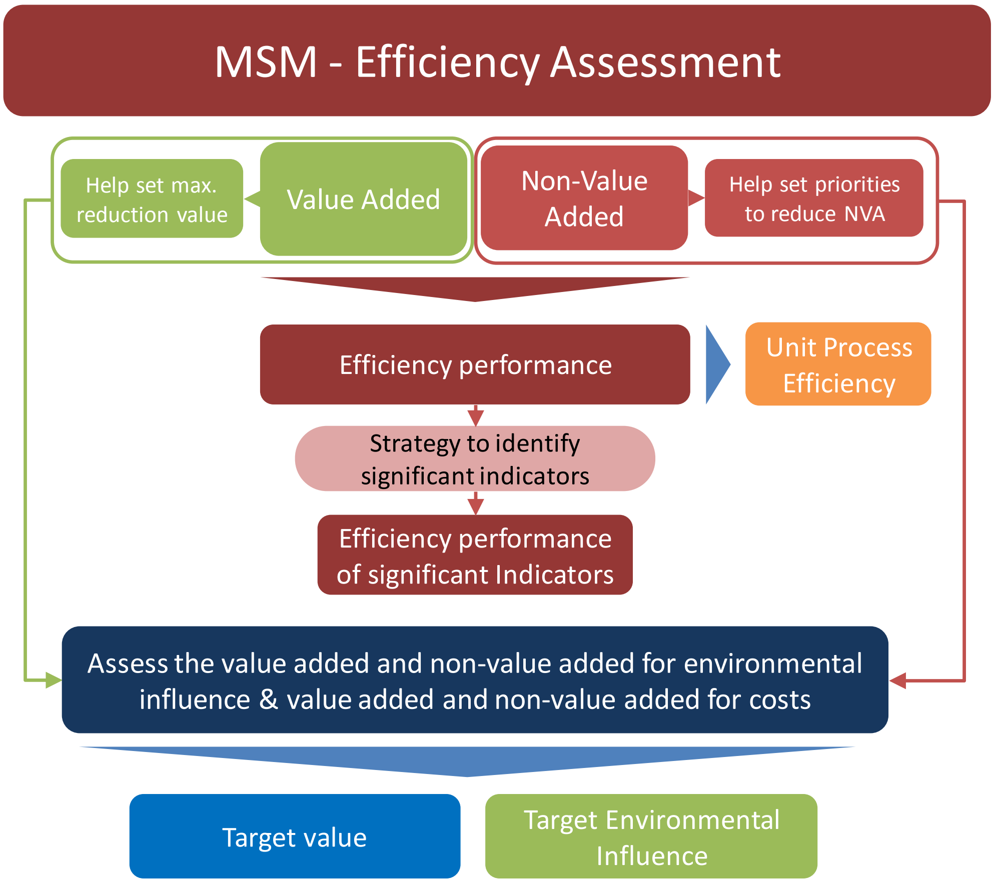

Figure 3 – Total Efficiency Index input results from MSM© methodology.

3.4 Normalised eco-efficiency

Concerning the eco-efficiency results and their normalisation, it is necessary to calculate within the Efficiency Framework, the ratio between the real and the target eco-efficiency for each unit process. This means that for each unit process, the real and target figures regarding the value dimension (€) and the environmental influence (Pt) should be quantified. Figure 4 presents the diagram corresponding to the input results from the ecoPROSYS© methodology.

The real eco-efficiency results are determined by the ratio between the real unit process value and the real environmental influence, while the target eco-efficiency results for each unit process are attained by the ratio between the value and environmental influence defined targets. The targets for value and environmental performance are a clear result from the integration of ecoPROSYS© and MSM©. As mentioned above, these results are the outcome of the quantification of environmental influence and costs using the VA and NVA dichotomy.

The normalised eco-efficiency result, for each unit process, is determined by the ratio between the real and the target eco-efficiency for each unit process. The normalised eco-efficiency result represents the percentage (%) of how the unit process fulfils the eco-efficiency performance for a predefined combination of targets (economic or monetary value and environmental influence).

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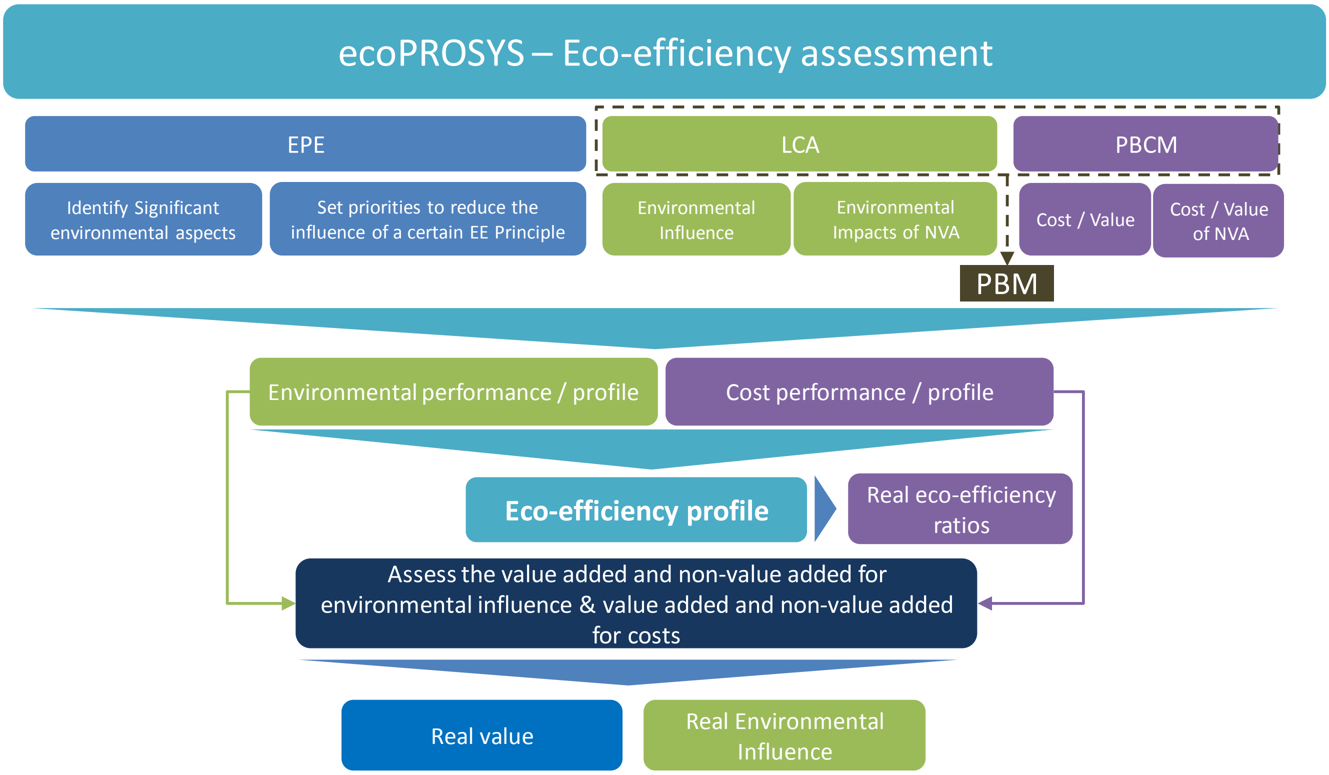

Figure 4 – Total Efficiency Index input results from ecoPROSYS© methodology.

During the normalisation of the eco-efficiency results, within the Efficiency Framework, the economic or monetary value and environmental influence efficiencies are also calculated. The value effectiveness (see equation 5) is determined by the ratio between the real and the target value, while the environmental influence effectiveness (see equation 6) is calculated by the ratio between the real and the target environmental influence. Both efficiency results are given as percentages. These results will support the decision making process, by helping on the quantification of the gap between real and target results for the value and environmental aspects.

An example of the Total Efficiency Index and the expanded diagram is shown in Figure 5. It is a mix of input data, € and Pt, with the % for the individual efficiencies calculus and its integration for each unit process and for the overall production process. The equations 1 to 6, define how the calculations presented in Figure 5 are obtained.

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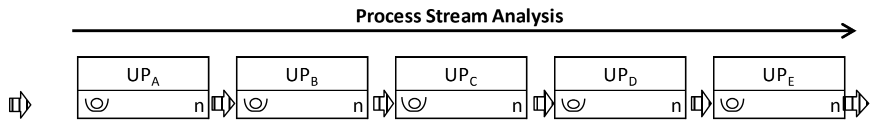

	UP A	UP B	UP C	UP D	UP E	
Total efficiency index	**54%**	**54%**	**48%**	**63%**	**54%**	**54%**
Real value (€)	10,00 €	12,00 €	15,00 €	9,00 €	20,00 €	66,00 €
Target value (€)	12,00 €	15,50 €	15,50 €	10,00 €	24,00 €	77,00 €
Value effectiveness (%)	**83%**	**77%**	**97%**	**90%**	**83%**	**86%**
Real environmental influence (Pt)	15,00 Pt	18,00 Pt	17,00 Pt	12,00 Pt	13,00 Pt	75,00 Pt
Target environmental influence (Pt)	13,00 Pt	15,00 Pt	12,00 Pt	11,00 Pt	10,00 Pt	61,00 Pt
Environmental Influence effectiveness (%)	**87%**	**83%**	**71%**	**92%**	**77%**	**81%**
Real eco-efficiency	0,667	0,667	0,882	0,750	1,538	0,88
Target eco-efficiency	0,923	1,033	1,292	0,909	2,400	1,26
Normalised Eco-Efficiency (%)	**72%**	**65%**	**68%**	**83%**	**64%**	**70%**
Unit Process Efficiency (%)	**74%**	**83%**	**71%**	**76%**	**84%**	**78%**

Figure 5 – Total Efficiency Index diagram for a given industrial example.

Figure 6 depicts in a graphical manner the results regarding eco-efficiency and efficiency performance for each unit processes presented in Figure 5. It is clear that the UP_E has the highest efficiency performance, yet UP_E is the unit process with the lowest eco-efficiency performance. Therefore, these results are important in order to support the decision making process and keep track, simultaneously, of eco-efficiency and efficiency performance, enabling managers to take actions that will improve both, efficiency and eco-efficiency performance.

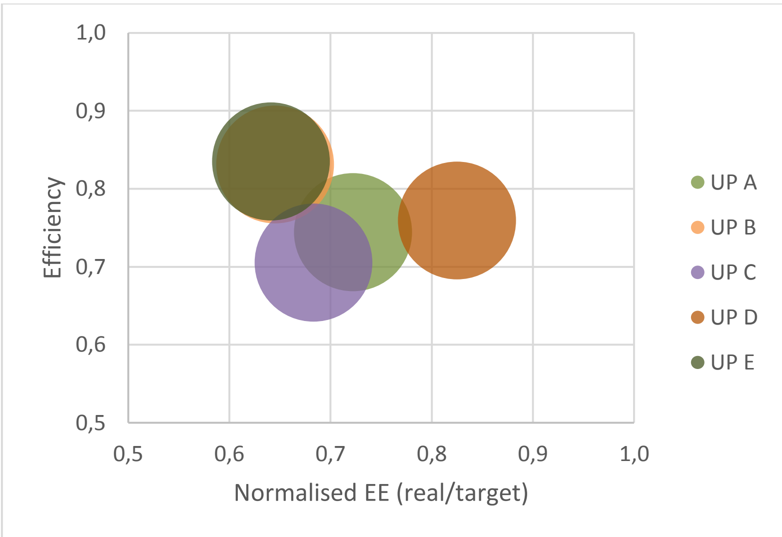

Figure 6 –Example of decision support plot (efficiency vs. Eco-efficiency performance)

3.5 Integration of Efficiency Assessment with Eco-Efficiency Principles

One other major output from the integration of the ecoPROSYS© and MSM© is the effectiveness measure of the eco-efficiency principles, i.e.:

- Reduce material intensity;
- Reduce energy intensity;
- Enhance recyclability;
- Reduce the toxic dispersion;

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- Maximize the use of renewable resources;
- Extend product durability;
- Increase service intensity.

In order to assess the effectiveness measure for each eco-efficiency principle, for a given unit process, and its integration for a sequence of unit processes, it is necessary to select the method that is more suitable to evaluate each eco-efficiency principle, namely ecoPROSYS© to perform the Environmental Performance Evaluation (EPE).

The environmental aspects are identified from the inventory, as a list of resources consumed or emissions discharged (process inputs/outputs), which are directly considered for the EPE. Consequently, the EPE is performed in order to enable the evaluation, according to a scale[6], of environmental aspects (e.g. consumption of materials) significance concerning each eco-efficiency principle, i.e. the affinity between the environmental aspect and the eco-efficiency principle. In addition, other parameters are considered to determine the environmental aspects significance, namely the environmental risk (frequency times the severity of the event) and the environmental influence spatial dimension. The outcomes of the EPE points out the set of significant and very significant environmental aspects and the respective eco-efficiency principle (see Baptista et al. 2016).

Subsequently, and in order to assess the effectiveness measure for each eco-efficiency principle, it is necessary to consider all (very) significant environmental aspects and their corresponding eco-efficiency principle(s), and consequently compute the average figure in terms of efficiency (already calculated with MSM©) for each eco-efficiency principle.

Figure 7 shows a practical example of the aggregated effectiveness measure according to each eco-efficiency principle, presenting the effectiveness measure results in a MSM©- like scorecard, both for each unit process, and for each eco-efficiency principle.

	UP_A	UP_B	UP_C	UP_D	UP_E	
Eco-efficiency principles	**67%**	**37%**	**91%**	**69%**	**53%**	**63%**
Reduce material intensity	80%	20%	94%	90%	20%	**61%**
Reduce energy intensity	90%	55%	89%	50%	40%	**65%**
Enhance recyclability	50%	77%	95%	85%	83%	**78%**
Reduce the toxic dispersion	75%	18%	85%	40%	35%	**51%**
Maximize the use of renewable resources	40%	15%	90%	80%	85%	**62%**
Extent product durability	-	-	-	66%	43%	**55%**
Increase service intensity	-	-	-	75%	65%	**70%**

Process Efficiency 100 - 90% | Process Efficiency 69 - 40%
Process Efficiency 89 - 70% | Process Efficiency <40%

Figure 7 – Effectiveness diagram for each eco-efficiency principle (example).

[6] VS – Very Significant Environmental Aspect; S - Significant Environmental Aspect; LS - Low Significance Environmental Aspect; NS - Non Significant Environmental Aspect

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4 Integrated framework

As previously described, the Efficiency Framework encompasses several modules, namely for assessing eco-efficiency (environmental influence and economic performance), resource and energy efficiency, and for simulating efficiency performance in order to optimize process efficiency. Ultimately, it must be stressed, that the cost and environmental influence of Non-value added (NVA) is one of the strongest link between the two methods – enabling trade-off analysis between both performance assessments and prioritize improvement actions, yet it is not the only link, as described in section 3.

Regarding its implementation, this means that methods behind both ecoPROSYS© and MSM© should be complementary and the exchange of information is possible to implement. Therefore, the basic parameters should be treated and assessed in the same way, in order to generate useful information to support decision making from the three main perspectives: environmental influence, economic performance and efficiency performance. Otherwise there is a significant risk of getting results without meaning, which could lead to wrong decisions.

In addition, the Efficiency Framework is not limited to eco-efficiency and efficiency assessments. Interactions with a proper and innovative Management System, as well as with Industrial Symbiosis concept and tools, aim to assure its correct implementation and guarantee an external dimension to the framework, allowing the identification of opportunities to increase value.

With this in mind, next sections outline the main opportunities and challenges to assure complementarity between the methods, as well as the main iterations of Efficiency Framework with both Management System and Industrial Symbiosis.

4.1 Integration of LCA & LCC in the Efficiency Framework

When challenged to define their position and contribution to sustainable development, companies have suggested the concept of **eco-efficiency**. By definition, Eco-efficiency is a management philosophy that encourages business to search for environmental improvements that yield parallel economic benefits (Madden, 2006). However, its main goal is much broader than just pursuing environmental improvements on resource use and pollution reduction. This is done by emphasising value creation for business and society at large, while providing competitive goods. In this sense, by increasing the value of goods, businesses tend to maximise resource productivity, gain bottom-line benefits, and reward shareholders, rather than simply minimising waste or pollution.

Therefore, for the application of the eco-efficiency approach, both economic and environmental aspects are extremely critical issues that need to be properly assessed to provide an appropriate support for decision making processes regarding production systems. The use and integration of LCA and LCC in the context of the MAESTRI Efficiency Framework is mainly related to the implementation of the eco-efficiency module.

The following sections describe the rationale of the integration of these two methodologies, as well as the main challenges and outcomes.

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4.1.1 Why applying Life cycle thinking?

Within sustainable manufacturing and product development approaches, life cycle thinking is considered as the most appropriate way to capture the full impacts and support decision-making process. Life Cycle Thinking (LCT) supports that environmental, economic and social assessment should go beyond the traditional focus on production site and manufacturing processes. It is based on the fact that products and services result from successive and interrelated stages, and usually different actors, that make up their life cycle. In this sense, it aims to provide a systematic and holistic perspective to products, processes or services, covering their entire life cycle from environmental, economic and social perspectives.

The main goal of LCT is to identify improvements by decreasing impacts across all life cycle stages of goods, production processes and/or services. Also shifting impacts from one stage to another should be avoided. This means minimising impacts at one stage of the life cycle, or in a geographic region, or even in a particular impact category, while helping to avoid increases elsewhere.

Overall, LCT can promote a more sustainable rate of production and consumption, including materials and energy consumption, by helping to use financial and natural resources more effectively.

4.1.1.1 Environmental Assessment

From an environmental perspective, Life cycle assessment (LCA) presents a structured, and principally comprehensive, approach to identify, quantify and assess the environmental aspects of product and/or production systems. Cornerstone to the life cycle thinking is the understanding that environmental impacts are not restricted to localities or single processes, but rather are consequences of the life-cycle design of products and services. The product life-cycle covers all processes from extraction of raw material, via production, use, and final treatment or valorisation.

In the context of the methodologies and tools described in the present report, as main outcomes an LCA can assist on:

- identifying opportunities to improve the environmental performance;
- decision making processes regarding environmental performance;
- selection of relevant indicators of environmental performance (i.e. KEPI);
- environmental communication and marketing (e.g. implementing an eco-labelling schemes, environmental claims, environmental product declaration, …).

Moreover, LCA is also a dynamic method that can be easily adapted to different product or production systems, industrial circumstances, geographies or perspectives, considering both full life cycle value chains (i.e. cradle-to-grave), or partial life cycle value chains (i.e. cradle-to-gate or gate-to-gate). The Efficiency Framework should be adjustable in order to assure its applicability to any process industry regardless of the type of industry/sector and the company size. For this reason, LCA will also provide flexibility and scalability to the environmental assessment, which are essential requirements regarding the MAESTRI Total Efficiency Framework, providing a life cycle approach.

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4.1.1.2 Economic Assessment

The term Life Cycle Cost generally refers to the "assessment of all the costs associated with the life cycle of a product that are directly covered by one or more of the participants in the product life cycle (supplier, producer, user/consumer, end-of-life actor), with complimentary inclusion of externalities that are anticipated to be internalized in the decision-relevant future" (Rebitzer et al. 2003). Its objective is to cover the assessments of costs in all steps of the product's life cycle, including the costs that are usually not expressed in the product market price such as costs incurred during the usage and disposal. LCC is essentially an evaluation tool in the sense that it provides important metrics for choosing the most cost-effective solution from a series of alternatives.

Several authors have used different approaches to the LCC methodology and applied it to a vast number of products, projects and machines, in different forms and extent. Despite the wide range of developed models found in the literature, there is a common aspect regarding most product LCC analyses: the scope is either on the product design and the impacts of design changes or on design alternatives throughout its life cycle. Moreover, the LCC method by itself, without additional assessments, is not sufficient as an indicator for sustainable practice (Rebitzer et al. 2003). Thus, it is also advised to evaluate the product on an environmental basis also with a life cycle approach, namely with LCA.

4.1.2 Challenges and guidelines for LCA & LCC integration

4.1.2.1 Similarities and differences between LCA & LCC

In production systems context, LCA and LCC share a common basic approach and partially common aims. Their main goal is to assess impacts over the whole life cycle and present the information in a manner that supports decision-making processes. However, despite the similarity of their approaches, LCC and LCA have important methodological differences. At the basis of these differences is mainly the fact that LCC and LCA are used as decision support methods in very different circumstances, which leads to differences in their scope and application. In this respect, while LCA evaluates the relative environmental performance of product and/or production systems, LCC evaluates the relative cost-effectiveness and/or the total cost of ownership.

For this reason, several aspects are treated differently or even ignored when LCA or LCC are applied separately. For instance, the important relationships and trade-offs between the economic and environmental performance are missed. On the one hand, regarding LCA in particular, it includes physical aspects that have no direct cost consequences and flows into or from processes from different life cycle stages other than those considered in LCC (e.g. flows related to extraction and production of raw materials and energy, waste treatment or emissions). On the other hand, the main factors central to LCC that are not considered in LCA include (Norris 2000):

- Cash flows related to investments;
- Costs and revenue streams which are not all proportional to, or even dependent upon, physical flows modelled in LCA;
- The timing of cash flows (costs and benefits), and the present valuation of these flows;
- The risks of costs, and their alteration or avoidance as a function of product/process design options.

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For this reason, the main conclusion is that important consequences arise from the environmental and economic analysis being applied separately. In fact, the influence and relevance of LCA when used for decision making is limited. Despite supporting decision making to certain extent, a company cannot afford to make decisions regarding alternatives just on a LCA basis, without considering economic aspects, product performance, quality aspects, production time, etc. In this respect, even in a situation where environmental performance is the only objective in a production and/or process design or decision, variable economic impact of alternatives must be considered in order to identify the decisions through which limited resources can achieve the best environmental performance. This is, in fact, the main goal of the eco-efficiency concept.

To summarize, the next table presents the main differences between LCA and LCC.

Table 1 - Main differences between LCA and LCC.

	LCA	LCC
Objective	Assess environmental performance of production systems or compare the environmental performance of alternative production system scenarios.	Assess production systems' cost-effectiveness or determine cost performance of alternative production system scenarios.
Method-approach	Generally top-down	Generally bottom-up
Life cycle scope	Activities comprising the entire life cycle.	Activities directly causing costs or benefits to the production system.
Time treatment and scope	All flows and their impacts are considered regardless of timing.	Time is a critical aspect to consider valuing (discounting) of costs and benefits.
Units for tracking flows	Physical and energy units.	Monetary units
Outcome units	Environmental impact and damage units.	Monetary units

Therefore, it becomes obvious that simply treating economic cost as just another flow within LCA does not provide a proper and fully integrated economic and environmental analysis. In practical terms, it requires the addition of a time dimension to the modelling for LCA, which is usually neglected. This means to introduce variables that have no causal dependence upon physical inventory flows, such as market costs or fluctuations.

Regarding LCC, its perspective depends largely on the stakeholder´s interest in the LCC results. For a specific stakeholder, the weight of each life cycle phase is not the same in the decision making process – the phases where the stakeholder really "holds" the costs are more important than the phases others (customer, end-user, etc.) will hold the costs. For that reason, it is common to attribute different weights to each life cycle phase in the LCC computation. Furthermore, the time variable is also important. The cost incurred during the years of the LCC object's life cycle have not the same financial impact in the decision making, even though some depreciation is taken into account. Due to these LCC characteristics it is important to look at LCC as a monetary performance indicator on a life cycle perspective when aiming its integration with LCA. The cost results should not be seen as

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a financial result or an accounting result but rather as a comparative indicator of cost burdens during the entire life cycle (likewise is considered for LCA). In this way the integration of LCC and LCA in a common metric, powered by process-based models (PBM) supplying the same resources consumed, for the same time lag and for the same system boundaries, is possible and a powerful tool for decision-making based on life cycle thinking.

4.1.2.2 LCA & LCC Integration Outcomes

As a conclusion from the previous sections, the main goal of integrating LCA and LCC is to feed the eco-efficiency module of the MAESTRI Efficiency Framework with relevant and accurate indicators regarding environmental and economic performance. In practice, by providing a life cycle perspective and approach, it is intended that both environmental and economic analysis are compatible, relatable and comparable. Then, by using methodologies with the same application principles, the main aim of this integration is to assure that the same scope is applied to both aspects.

In fact, to consider the same scope is a critical issue when both LCA and LCC are applied to a production system, in particular when both methodologies are integrated. The main consequence of neglecting this aspect is to neutralise the relationship between economic and environmental performance, which would probably lead to incorrect results and wrong decisions. In this respect, special attention should be given to parameters such as the functional unit or the assessment boundaries of the analysis.

The life cycle of production systems is usually composed by unit processes, connected by flows of intermediate products, which perform one or more defined functions. In both LCA and LCC this is called the product or production system. The definition and characterisation of a product system can represent a very difficult task, considering the complexity of certain production systems. Ideally, all the inputs and outputs necessary to assure the defined function of a production system should be considered. However, if all flows are followed until they have been reduced to elementary flows, this would result in systems too large and complex to describe and evaluate. The problem becomes even more complex when physical and geographic limitations are inherent to the production system, which happens frequently. Therefore, delimitations within the technological system must be defined.

In life cycle based methodologies, the definition of the product system delimitations is usually called the definition of assessment boundaries. The assessment boundaries determine, from the entire production system life cycle, which unit processes and flows shall be included within the scope of the assessment. One evident simplification is to exclude all activities that have negligible effects on the results. Also, when comparing alternative scenarios, activities that are identical in the compared alternatives can be omitted. However, this "simplification" should be made with particular caution, as the details of production system mapping may significantly influence the results. In this respect, the rationale is that the more detailed the mapping of the production system is, greater will be the advantage taken from the framework and the more comprehensible will be the results. For that purpose, a balance between the assessment objectives and the complexity of the production system should be found in order to make the interpretation of results easier, considering namely the goal and purpose of the assessment, the scope of its implementation, the defined functional unit, the intended outcomes, the target audience, etc.

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Moreover, regarding the assessment scope, both direct and indirect aspects should be considered. Taking into account the source and its consequential impact, direct aspects are all the aspects that can be controlled directly by the company and/or on which the company has a direct influence. This includes, among others, consumption of energy and resources, gaseous and water emissions, produced residues, labour, equipment maintenance aspects, as well as downstream stages whenever the end-of-life and routing is under direct control. On the other hand, indirect aspects are those that are related to the activities included in the system under analysis, but occur in premises owned or controlled by third parties and in which the company cannot exert direct influence, e.g. upstream stages related to raw materials and consumable goods production.

The functional unit is another important aspect to assure that the same scope is applied to both environmental and economic aspects. In both LCA and LCC, product systems are evaluated on a functionally equivalent basis. In this respect, the concept of a functional unit is used to normalize the data based on equivalent use and to provide a reference for relating production system inputs and outputs. Also across different alternatives, the functional unit is used to assure that different alternatives are comparable.

The PBM described in D.2.1 is the proper modelling tool to assure a balanced and complete assessment of costs and environmental influence. By modelling each process involved in each considered life cycle phase, under a unique scope and boundaries, the PBM outputs the resources consumed (materials, energy, consumables, residues, etc.) and the required machine/operators time. These are inputs to be processed by the LCC and LCA, which will translate them into monetary values and environmental influence. All the considered streams are taken into account for the same time span and for the same exploration considerations, making it possible to integrate LCC and LCA respecting the life cycle thinking principles.

Concluding, the overall aim of integrating LCA and LCC in the MAESTRI Efficiency Framework context, is to provide evidences to support decision making process pursuing both economic efficiency, which should also have positive environmental benefits and environmental efficiency, which should also have positive economic benefits. Therefore, it aims to provide a solid and robust setup, allowing the use of MAESTRI Efficiency Framework in different situations, by allowing the definition of trade-offs and relationships such as:

- Which variables within the system provides the greatest combined economic and environmental leverage?
- What are the critical limits that should influence the decision-making?
- What are the incremental costs/benefits of a specific environmental improvement?
- Which option provides the greatest environmental improvement per euro?
- How low must the investment cost for a particular environmental improvement be to become cost-effective?
- What environmental and economic aspects should be prioritised in terms of production system performance improvement?
- How feasible are the targets defined for production system performance improvement?

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4.2 Integration of Eco Orbit View in the Efficiency Framework

Eco Orbit View (EOV) is a simple method intended to choose potential improvement areas from the production process where the company may perform an improvement project in order to simultaneously improve business and environmental performance. The key aspects for choosing the potential improvement areas are:

1. The potential improvement area refers simultaneously to the eco-efficiency and monetary benefits (business goals supporting quality, cost, delivery aspects);
2. The potential improvement area reflects the priorities of the management team in the company and the strategic goals.

The name Eco Orbit View originates from space exploration and reflects the idea that the Earth, seen from an orbital spacecraft reveals only the largest objects like oceans, mountain chains, etc. The infinite complexity of details remains hidden. Likewise, the proper judgement about the state of a production process can be made without complex analysis of data thanks to focusing on the methodologically selected key aspects.

An Eco Orbit View analysis is performed in 4 steps:

1. Identify production process steps
2. Identify Key Performance Indicators (KPIs) relevant for each process step
3. Identify Key Environmental Performance Indicators (KEPIs) relevant for each process step
4. Identify links between KPIs and KEPIs

In summary, the Eco Orbit View shows KPIs (reflecting company needs) and KEPIs (reflecting environmental needs) side by side for chosen process steps. The analysis results in the indication of potential improvement areas, reflecting the needs of the company to improve both the economic and environmental performance. Thus, the areas where the eco-efficiency of the company may be improved can be identified.

4.2.1 The relationship between eco-efficiency principles and lean management principles

Companies can be an active partner in creating true eco-efficiencies that add value and reduce costs (WBCSD, 2010). In agreement with the value-based paradigm they can improve eco-efficiencies by focusing on three objectives (WBCSD, 2000):

- O1. Reduction of the consumption of resources (minimization of energy, material, water and land use; an increase of recyclability and durability of goods),
- O2. Reduction of the impact on nature (minimization of air emission, waste disposal, water discharges as well as promoting the consumption of renewable resources),
- O3. Increasing the product or service value (greater benefits for customers with less material and resource use, selling the service instead of selling the product).

The eco-efficiency concept brings together two dimensions of economy and ecology described by the eco-efficiency ratio (WBCSD, 2000):

$$eco-efficiency = \frac{\text{Product or service value}}{\text{Environmental influence}} \quad (7)$$

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The value of a product or service delivered by a company, sector or economy as a whole represents the economic perspective, whereas the environmental influence being a sum of environmental pressures generated by the company, sector or economy represents the environmental perspective (OECD, 1998). Eco-efficiency therefore aims to create more value with less environmental influence.

"Doing more with less" is frequently used to describe the purpose and scope of the eco-efficiency (WBCSD, 2000). The same quote accompanies the Lean Management approach, which is commonly used to organize and manage the production and supporting processes in manufacturing industry. The core of the Lean concept is to maximize value by minimizing all activities that are perceived as wasteful (not adding value to the product or service) (Womack and Jones, 1996). Every step in the process should be evaluated regarding whether it adds value to the product or service (VA: value added activities) or does not add value to the product or service (NVA: non-value added activities). Non-value added steps should be eliminated or minimized (Rother and Shook, 2003). This evaluation procedure allows looking at the processes through the value and waste lens. Companies that will focus on the everyday improvement of value delivery and elimination of waste are expected to be capable to do more using less resources.

Both approaches are guided by a set of principles (Table 2). The WSCSD (2000) identifies seven eco-efficiency principles that should be followed by any company willing to deliver more value with less resource consumption. Whereas according to Lean Management the company aiming at the same purpose should follow five lean thinking principles (Womack and Jones, 1996).

Table 2 - Description of 7 eco-efficiency principles and 5 Lean Principles.

7 Eco-efficiency Principles	5 Lean Principles
1. Reduce material intensity 2. Reduce energy intensity 3. Enhance recyclability 4. Reduce the toxic dispersion 5. Maximize the use of renewable resources 6. Extent product durability 7. Increase service intensity	1. Precisely specify value for specific product/service 2. Identify the value stream for each product/service 3. Make value flow without interruptions 4. Let the customer pull value 5. Pursue perfection

The starting point for the improvement of the eco-efficiency performance is to focus on the reduction of negative environmental influence (denominator of the eco-efficiency ratio). Principles 1-5 represents two eco-efficiency objectives. The first eco-efficiency objective, i.e. reduction of the use of resources, is represented by the principles 1, 2 and 3, whereas the second eco-efficiency objective, i.e. reduction of the impact on nature, is represented by the principles 4 and 5. The last two principles correspond to the third eco-efficiency objective i.e. enhancing product or service value (numerator of the eco-efficiency ratio).

On the other hand, the starting point for Lean Management is precisely specified value. Value should be defined by the customer and is emerges when the product or service meets the customer's needs at a specific price at a specific time. As Womack and Jones (1996) state '*lean thinking therefore must start with a conscious attempt to precisely define value in terms of specific products with specific capabilities offered at specific price through a*

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dialogue with a specific customer' (p. 19). Identifying the value stream for a product or service is the second Lean principle. Womack and Jones (1996) stress that implementing this principle almost always 'exposes enormous, indeed staggering, amounts of waste' (p. 19). Process steps that are non-value added should be eliminated or at least reduced to the minimum. The value stream containing value added and reduced non-value added steps is the input for the next principle, which aims at creating a smooth flow of value. The product or service flows smoothly towards the customer when value added steps occur in tight sequence with minimal delays and interruptions. According to the fourth principle, it is the customer that should pull value from the upstream activity. This opposes the push-alike idea of delivering (pushing) products/services, often unwanted, onto the customer. According to the last principle the company should pursue perfection by continuing to work in line with the principles until perfect value is created without waste.

Eco-efficiency principles as well as Lean Principles refer broadly to the two categories: value and waste. The eco-efficiency value of the product or service can be increased by extending product durability and increasing service intensity; and it can be enhanced by lowering the inputs of materials, energy and reducing emissions. Consequently, the eco-efficiency approach can be described in terms of delivering product and service value and minimizing the environmental wastes. Similarly, Lean value of the product or service represents the customer's needs met at a specific price and time and can be enhanced by the elimination or minimization of waste. Lean wastes are categorized into seven categories: overproduction, unnecessary inventory, unnecessary transport, unnecessary motion, defects, inappropriate processing, waiting (Ohno, 1988). Interlinks between the eco-efficiency approach and the lean approach are presented in Figure 8.

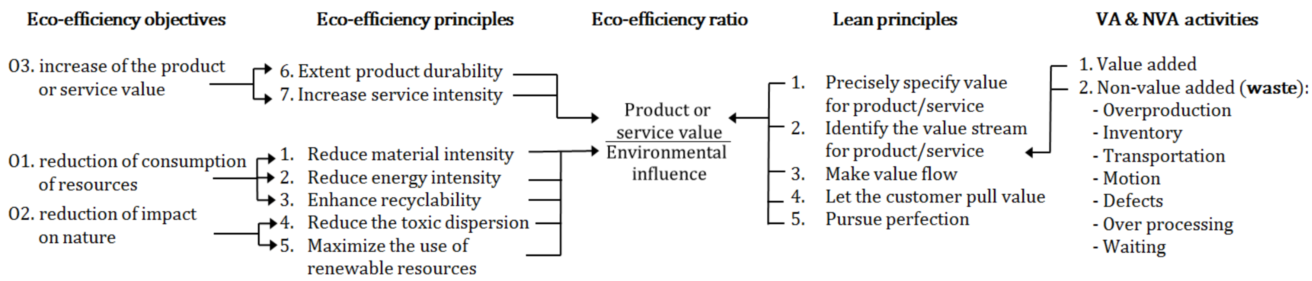

Figure 8 - Interlinks between eco-efficiency and lean approaches.

Eco-efficiency and lean approaches are strongly interrelated and derived from the same value-based paradigm. Responding to the question what is the difference between those two, the authors of the book Creating a Lean and Green Business System (Zokaei et al., 2013) state that 'apart from the fact that individual customers are multiplied to become society and environmental wastes have slightly different character than the traditional lean wastes, not a lot' (p. 44).

Like other Lean wastes, environmental wastes do not add value from the customer's point of view. They also frequently represent costs to the company and society in general. Lean Management can lead to significant environmental benefits, since environmental wastes are related to Ohno's seven waste categories. The US Environmental Protection Agency (EPA) lists the environmental influence of these wastes (see Table 3).

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Table 3 - Environmental influence of lean wastes (Source: EPA (2007). The Lean and Environment Toolkit. Retrieved from http://www.epa.gov/lean).

Waste Type	Environmental Influence
Overproduction	• More raw materials and energy consumed in making the unnecessary products • Extra products may spoil or become obsolete requiring disposal • Extra use of hazardous materials results in extra emissions, waste disposal, worker exposure, etc.
Inventory	• More packaging to store work-in-process (WIP) • Waste from deterioration or damage due to stored WIP • More materials needed to replace damaged WIP • More energy used to heat, cool, and light inventory space
Transportation and Motion	• More energy use for transport • Emissions from transport • More space required for WIP movement, increasing lighting, heating, and cooling demand and energy consumption • More packaging required to protect components during movement • Damage and spills during transport • Transportation of hazardous materials requires special shipping and packaging to prevent risk during accidents
Defects	• Raw materials and energy consumed in making defective products • Defective components require recycling or disposal • More space required for rework and repair, increasing energy use for heating, cooling and lighting
Over processing	• More parts and raw materials consumed per unit of production • Unnecessary processing increases wastes, energy use, and emissions
Waiting	• Potential material spoilage or component damage causing waste • Wasted energy from heating, cooling, and lighting during production downtime

Despite the clear relationship between lean and eco-efficiency approaches, the companies often overlook opportunities to prevent or reduce environmental wastes and perceive the approaches as additive or complementary to each other. The awareness of the linkages between Lean Management and eco-efficiency may help to ensure that the reduction of lean wastes entails the reduction of environmental wastes.

4.2.2 Relationship between Eco Orbit & MSM ©

Multilayer Stream Mapping (MSM©) and Eco Orbit View are both methods for the assessment of the production process, but they vary quite significantly regarding the scope and the purpose. The most important features of these methods are compared in table 4.

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Table 4 - Comparison between Eco Orbit View and MSM©

	Eco Orbit View	MSM©
METHOD		
Type of output	Indicates the processes where the implementation of improvement projects: - Is significant from strategic point of view; - Will impact both business goals and eco aspects with the same actions; – Will deliver meaningful benefits to the company in both aspects.	Indicates the processes with: – Low value creation/low efficiency – Avoidable environmental impacts – Major potential for improvement – Unnecessary costs due to inefficiencies/major misuses – Higher efficiency in terms of environmental, economic and production aspects for each unit process Indicates: – Value addition versus not adding value – Within a production system, "where" and "how much" can a unit process and/or a production system improve its financial, environmental and performance aspects – Simplified ROI for improvement actions analysis (payback)
How to use	1. During a workshop to create a common understanding of ecological issues among all levels of employees. 2. Reviewed and visualised on shop floor	1. As a dashboard for periodical review for managers during meetings, in order to keep track of targets and define improvement strategies, i.e. reduce missuses 2. As a daily visualisation on shop floor to keep track of targets
Scope	Companies' operational performance regarding quality, cost, delivery. Eco efficiency of the company.	Productivity and efficiency of a production system. Eco efficiency of the company.
PEOPLE		
Target group	Operators to middle-management	Top-management to middle-management and operators
Team knowledge/ expertise need for implementation	Medium	High (mainly to be able to define the VA and NVA)
INPUT		
Operational maturity level of the company	Low to high	Medium to high
Amount of data needed about the production process	Small	Large
Sources of data needed about production processes	Shop floor visit, employees interview, strategy, performance management system (if in place)	Performance management system, measuring equipment data (i.e. electricity meter), MES, ERP.
Input needed	- Production process steps - Strategic objectives and management team's priorities - Key Performance Indicators (KPI) - Significant ecological aspects, Key Environmental Performance Indicators (KEPI).	- Production process steps - Target value vs. actual value for each category variable for each process step - Process parameters: energy, materials, water, consumables, waste, emissions, etc. - Operational parameters: machine speed losses; machine availability; process temperature; product dimensions; quality, etc.

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	Eco Orbit View	MSM©
TIMEFRAME		
Time of preparation (before assessment starts)	No time needed	1-2 weeks (depends on the case study and number of variables to be assessed)
Time of analysis	One day	Several Weeks
Time of implementation	1-2 days	2-3 weeks (depends on the case study and number of variables to be assessed)
Readiness of output	1-2 days	Immediately

Although MSM© and EOV demonstrate some similarities, for instance selecting proper aspects for analysis, they remain complementary approaches. EOV is designed as a quick, simple assessment method which can be performed during a workshop of a few days. It requires a basic understanding of the company's KPIs and KEPIs and interlinks between them in order to identify the potential improvement areas. MSM© delivers much more complex output information, it requires more data, more preparation and higher expertise of employee's.

4.2.3 Procedure and key aspects to define variables and indicators for eco-efficiency and efficiency assessment within Eco Orbit View

Eco Orbit View needs a definition of KPIs and KEPIs for each process step. The procedure of choosing indicators for the assessment may vary depending on the company's complexity and their maturity level.

If a Performance Management System (PMS) is already in place and KPIs are well defined and monitored, the use of the existing indicators for the EOV analysis is recommended. In case that a PMS is not in place or the available indicators are not sufficient, there is a need to assist the company in defining relevant KPIs. This can be done by supporting a focused discussion with management team. The discussion starts with conversation about the company's strategy and the goals. Based on that, the set of KPIs relevant to the company's strategy and goals may be defined and obtained. Then facilitator suggests considering other KPIs, which are not directly connected to the current strategy, but may be of high relevance to the company's vision and plan regarding economic and environmental performance. This is maybe the case of the companies which currently do not have PMS in place and goals regarding environmental performance, but would like to change it with the help of EOV.

Defining or choosing KEPIs should be done in an analogous way. If the company follows the ISO 14000 standard, significant environmental aspects from the ISO may be used as a baseline for KEPI definition. If the company does not have significant environmental aspects identified, EOV will guide the company to identify the proper ones. The base for that is the analysis of the 8 green wastes (eco wastes) identified by Zokaei et al. (2013) (table 5).

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Table 5 - Examples of eco aspects from the injection moulding domain, identified based on 8 eco wastes

Eco waste	Associated eco aspects used for further KEPIs definition
1. Energy Consumption	Energy consumption by machines
	Compressed air to operate the runner (% of whole compressed air used in factory related to the production line)
	Energy for cooling water (% of energy used for cooling for the production vs. for the whole factory)
2. Physical Wastes	No. of rejected parts (production scrap, destructive test)
	Non-processed plastic
	Grease from the machine
	Cleaning materials
3. Water Usage	Water used for cooling (loss for evaporation)
4. Air Emissions	Diffuse emission from melting the plastic
5. Land contamination	-
6. Discharges to Water	-
7. Noise and Nuisance	Noise from the injection machines
8. Lost People Potential	Not enough operators' empowerment

A more detailed description of the strategy to define indicators for eco-efficiency and efficiency assessment within an Eco Orbit View analysis will be provided in the Deliverable 3.2 “Management system framework for Continuous Improvement in process industries”.

4.3 Integration with Industrial Symbiosis concept

Industrial Symbiosis (IS) “engages traditionally separate industries in a collective approach to competitive advantage involving physical exchange of materials, energy, water and by-products” (Chertow, 2000). The definition of IS has been extended in scope to consider those cases in which IS may occur within a single company or industry alongside with multi-company and multi-industry cases (Short et al., 2014). On this basis, the interaction of Industrial Symbiosis with eco-efficiency and efficiency has been analysed within MAESTRI project and addresses the application of an Industrial Symbiosis approach from a single company perspective.

The benefits of applying Industrial Symbiosis for a company can be manifold. According to WRAP (2014), from an environmental perspective it can reduce carbon emissions, the consumption of raw materials and the cost of waste disposal while diverting waste from landfill. The same study recognises positive aspects from an economic perspective by new revenue generated from residues and by-products and by opening up the company to new business opportunities.

This section explores the envisaged interaction between Industrial Symbiosis and eco-efficiency and efficiency analysis within the MAESTRI project. It focuses on the links between the expected outputs of WP4, namely a library of case studies on Industrial Symbiosis and a

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toolkit to support the application of Industrial Symbiosis, and the eco-efficiency and efficiency methodologies and tools.

4.3.1 Foreseen strategy to use eco-efficiency and efficiency results for Industrial Symbiosis

There is an envisaged linkage between some of the results of WP4 activities, particularly in regard to Tasks 4.2 (Library of case studies and open source database of waste) and 4.3 (Toolkit for Industrial Symbiosis (T4IS) with the four HOW TOs). These results will be a library of case studies in Industrial Symbiosis and a toolkit to support the implementation of Industrial Symbiosis in manufacturing companies. The toolkit will be developed according to four guiding questions:

- How to see waste?
- How to characterise waste?
- How to value waste?
- How to exploit waste?

The main connections between eco-efficiency and efficiency results have been identified so far with respect to the first two questions. In this sense, the identification of process waste (MSM©) and of residues (ecoPROSYS©) can contribute, together with a value analysis tool (under development in WP4), to the first question: "how to see waste?". The LCA analysis within the ecoPROSYS© methodology can give support to the second question: "how to characterise waste?". These linkages are illustrated in Figure 9 and explained in more details herein.

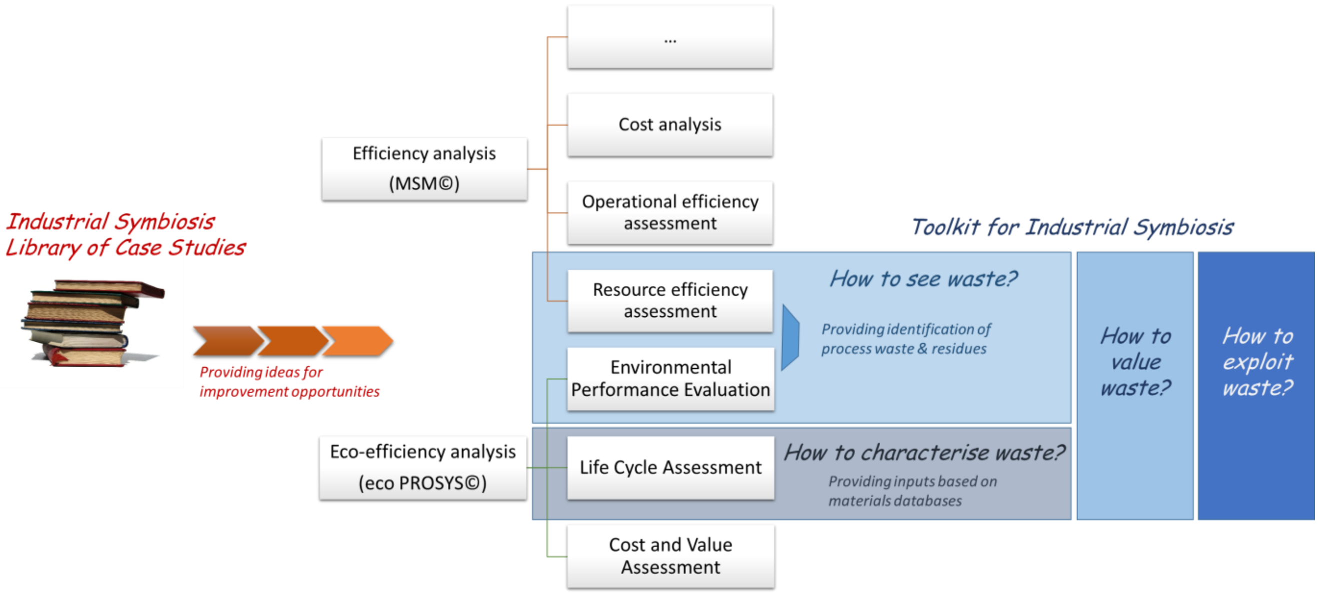

Figure 9. Visualisation of the interaction between Industrial Symbiosis library/tools and MSM© and ecoPROSYS©.

MSM© has the potential to provide a multi-dimensional analysis, including resource efficiency, operational efficiency and cost analysis, among other possibilities. Concretely, the resource efficiency analysis will provide useful information to identify process waste and it can contribute to the "How to see waste" tool within the WP4 toolkit for Industrial Symbiosis.

The Environmental Performance Evaluation from ecoPROSYS© methodology is a process analysis of environmental aspects to characterize the intensity and significance of

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environmental aspects according the eco-efficiency principles. This evaluation will result in the identification of residues at factory level and thus, providing additional information for the WP4 toolkit for Industrial Symbiosis on How to see waste.

LCA is a well-known tool for environmental impact assessment and has also been applied to Industrial Symbiosis. Previous use of LCA in relation to Industrial Symbiosis was reported in D1.2.[7] The main uses were the following:

- to analyse and compare different designs of Industrial Symbiosis (Singh et al., 2007; Sokka et al., 2010; LIU et al., 2011);
- to provide input data on the estimated sector average reference case for a variety of products (MATTILA et al., 2012);
- to perform a quantitative analysis of the CO2 emissions from different cement production systems and products, both existing and hypothetical (AMMENBERG et al., 2015).

The application of the LCA methodology within ecoPROSYS© can contribute to the "How to characterise waste" tool within the WP4 toolkit for Industrial Symbiosis. In particular, the LCA database can provide information on the content of material waste (in the case of scrap production or by-products) and this would be complemented with information from the manufacturing processes that modified the material in the factory. The characterisation of waste materials by using the LCA materials database is a hypothesis that will be further tested within the future project steps.

Finally, a connection has also been identified between the results of WP4 and the eco-efficiency and efficiency analysis. This linkage is also illustrated in Figure 9. The library of Industrial Symbiosis case studies can provide: (i) information for the environmental performance evaluation and (ii) ideas for improvement opportunities, both within the ecoPROSYS© methodology. The application of these improvement opportunities could be evaluated using the simulation tool to be developed within the MAESTRI project as part of WP2.

4.4 Outline of the Efficiency Framework

The Efficiency Framework of MAESTRI will allow an original and practical integration of eco-efficiency analysis, including LCA and cost analysis component alongside with process efficiency (or operational efficiency) on the perspective of Lean Manufacturing, thus implicitly evaluating "value added" and "non-value added" (waste) actions and resource usage (Figure 10). The pillars for this integration, the ecoPROSYS© and MSM© methodologies provide the necessary inputs and interconnection capabilities for this endeavour, since their algorithms correspond to state-of-the-art strategies for industrial management including the environmental and economic analysis. Furthermore, the algorithms fundamentals are designed in a modular way, allowing extensions, thus facilitating their adaptation to different industrial sectors or specific types of companies. For instance, in MSM©, the multi-domain analysis can be easily extended by creating more domains for the efficiency assessment

[7] Deliverable 1.2 on Technology Watch Report

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besides the already validated resource efficiency and operation variables efficiency domains, e.g. for the flow domain (logistic variables analysis integration). The MSM© has also proven its flexibility by applying its base conceptual algorithm and scorecard construction for assessing, in a practical way, the normalization of eco-efficiency ratios (described above), to create the Total Efficiency Index, or to measure and display the aggregated efficiency of the eco-efficiency principles in a given process sequence. Likewise, the ecoPROSYS© methodology allows flexibility in its application and adaptation to different sectors and companies, either from the modular approach applied for the complexity level of calculus, both for the economic value and cost assessment (from more simple cost assessment to full LCC analysis), and for the environmental impact assessment (from simplified LCA to full LCA analysis).

The interconnection between the Management System (WP3) and the operational efficiency was already described above, namely by the affinity of a key tool to be applied in the project Eco Orbit View with MSM capabilities, namely for the sharing of the Lean Principles and Lean Thinking approach, but also to use ecoPROSYS© for the environmental assessment. On the other hand, the Industrial Symbiosis domain has also clear affinities both to MSM© application outcomes, for instance providing a practical tool for supporting "how to see waste", but also with ecoPROSYS©, namely on the LCA analysis for the environmental assessment that will be supporting part of "how to characterize waste". The full development and algorithms explanation of these interconnections will be presented in outcomes of Task 2.3 (Simulation and decision support module).

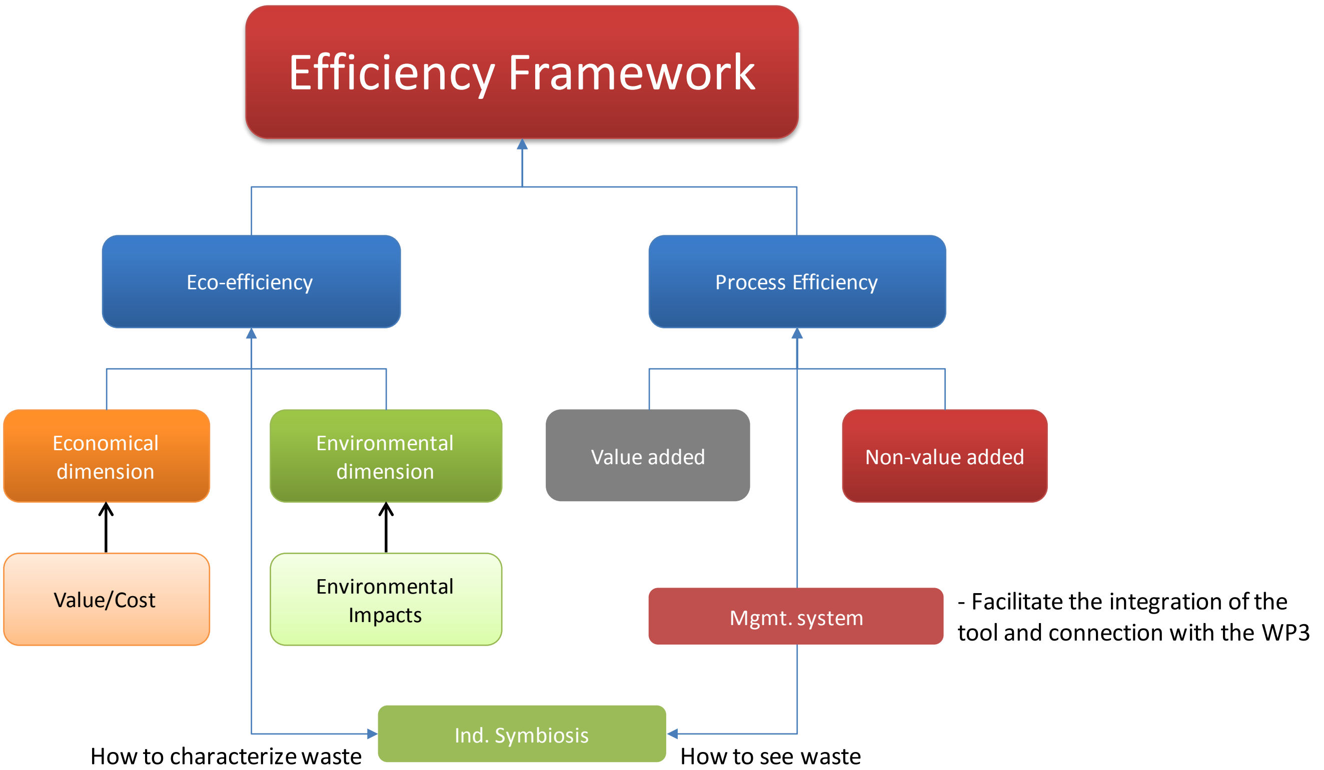

Figure 10 – Efficiency Framework diagram with interconnections to the Industrial Symbiosis and Management System Pillars of MAESTRI.

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5 Final remarks

The main goal of WP2 is to develop the MAESTRI Efficiency Framework, which encompasses several modules, namely for assessing: i) eco-efficiency (environmental influence in relation to economic performance); ii) resource and energy efficiency; iii) overall efficiency assessment. Moreover, at its genesis, WP2 is strongly connected to WP3 and WP4, since its developments and integrated framework are aligned with the developments regarding the Management System and the Industrial Symbiosis approach.

Conceptually, WP2 aims at the integration of different aspects results: eco-efficiency, operational efficiency, value and waste identification, strategy deployment for continuous improvement and change management, etc. For this reason, a new approach was developed, which enables the Efficiency Framework to be used in an integrated way to assess eco-efficiency and efficiency performance, and overall production system efficiency. As its main objective, the integration of the Efficiency Framework should empower a flexible and straightforward analysis, facilitating a company's implementation and use of the integrated framework (regardless of the size and sector of the company). Its originality is founded not only on the integration of results of two original methodologies (ecoPROSYS© and MSM©), but also on the creation of a relationship and explicit perspective for the concurrent assessment of eco-efficiency (including LCA and LCC aspects) and operational efficiency (with foundations on Lean Manufacturing's value/waste assessment) with focus on the creation of practical and user-friendly analysis tools.

From the integration of results from both methodologies, a new MAESTRI metric has been defined, the so called **"Total Efficiency Index".** This proposed new index is calculated for each unit process of the production system under assessment and can be integrated for the complete production process of a given product (hierarchical pyramidal integration of each level's results). The logic behind this metric is to combine two fundamental efficiency aspects, namely **eco-efficiency**, which considers the ecology and economy (with the ecoPROSYS© methodology), and **operational efficiency**, which considers the NVA and VA actions in respect to the Lean Principles application (by MSM© methodology).

However, due to the several and complex differences between the original methods used in both methodologies, strong efforts will be assigned to make sure that the integration is made in a way that enables proper production system assessment and comparisons. At the basis of these differences is mainly the fact that VSM (as part of MSM©) as well as LCA and LCC (as part of ecoPROSYS©) are used as decision support methods in very different circumstances, which leads to differences in their scope and application. For this reason, it is imperative to assure their correct implementation to provide an accurate determination of the above mentioned index (Total Efficiency Index) considering the existing settings of different sectors of process industries.

Regarding lean approaches, apart from being obviously related to process efficiency methods, they are also strongly interrelated with eco-efficiency, as they were derived from the same value-based paradigm. For this reason, the awareness of the linkages between

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Lean Management and Eco-efficiency helps to ensure that the reduction of lean wastes entail the reduction of environmental wastes. However, the greatest impact of delivering value to the customer and society in general, and maintaining economic growth with reduced environmental influence will be achieved from the full integration of eco-efficiency and lean approaches.

Concerning the process efficiency methods, although MSM© and Eco Orbit View demonstrate several similarities, for instance selecting proper aspects for analysis, they mainly remain as complementary approaches. EOV is designed as a quick, simple assessment method which can be applied during a few days' workshop. It requires a basic understanding of the company's KPIs and KEPIs and interlinks between them, in order to identify the potential improvement areas. On the contrary, MSM© delivers much more complex output information, but also requires more data, more preparation and higher expertise of employee's.

Finally, the interaction with Industrial Symbiosis will mainly be based on the four guiding questions defined to develop the Industrial Symbiosis toolkit:

- How to see waste?
- How to characterise waste?
- How to value waste?
- How to exploit waste?

The interactions between the first two questions and MSM© and ecoPROSYS© were initially identified. Concretely, the identification of waste (MSM©) and of residues (ecoPROSYS©) can contribute, together with a value analysis tool (under development in WP4), to answer the question "how to see waste". Moreover, the LCA analysis within the ecoPROSYS© methodology can give support to "how to characterise waste". The latter interaction is based on the hypothesis that the characterisation of waste materials can be done by using the LCA materials database, and this will be further tested within project activities.

Additionally, the library of Industrial Symbiosis case studies could provide: (i) information for the environmental performance evaluation and (ii) ideas for improvement opportunities, both to be used within the ecoPROSYS© methodology. The application of these improvement opportunities could be evaluated using the simulation tool to be developed within MAESTRI project as part of WP2.

Concluding, the Efficiency Framework of MAESTRI aims to allow an innovative and practical integration of eco-efficiency analysis, including LCA and LCC, with process efficiency (or operational efficiency) analysis from the perspective of Lean Manufacturing, thus implicitly evaluating "value added" and "non-value added" (waste) actions and resource usage.

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