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Procedia CIRP 00 (2015) 000–000

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The 22nd CIRP conference on Life Cycle Engineering

Assessing the environmental performance of machine tools – Case studies applying the 'LCA to go' webtool

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Abstract

A simple, sector specific webtool was developed within the EU funded 'LCA to go' project, to enable SMEs to perform first environmental assessments of their industrial machines and machine tools. The tool was applied together with several SMEs, sixteen of which provided feedback on their user experience, applicability, value of the results and future plans with the tool. The software flow of the webtool is presented together with a summary of the outcome of the case studies. Based on the feedback and the application of the webtool further development options for the sector specific tool were developed.

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Keywords: SME; LCA; environmental assessment; machine tools.

1. Introduction

The increasing interest in environmental impacts of products over the whole life cycle is reflected by the numerous existing standards and many ongoing activities in this field. Large sized companies have enough budget and workforce to fulfill the existing and upcoming environmental requirements, but what about SMEs? The objective of the project 'LCA to go' is to develop a free webtool for SMEs, enabling them to perform a sector specific life cycle based environmental assessment. It provides tailor-made solutions to integrate simplified life cycle approaches into daily business processes in six sectors. Among other sectors, the 'LCA to go' project focuses on Industrial machines and more specifically machine tools. This paper describes the needs of the target group identified in previous research, uses a fictitious example to walk through the structure and functionality of the tool, and provides a summary of feedback on the first application of the tool. The user experience is analyzed on the basis of 16 case studies from across Europe to identify the barriers and lessons learnt.

2. Target group

For machine tool producers, the main environmental and cost implications of their products occur beyond the own factory walls – mainly during the 'Use' phase of the machines they produce [1]. Customers of these companies are aware of this fact, making it an important topic for these producers. As described by the case study companies, engaging customers regarding the impact of the machine tools over the entire life cycle is seen as proactive, forward-thinking and customer needs oriented. To provide SMEs with the capability to fulfil these customer requirements, a survey was carried out from May to September 2011 in the context of the 'LCA to go' project. The survey showed that environmental issues are to a certain extent considered in SMEs but that they have very little practical experience of LCA. The requirements of the SMEs identified through a 'needs assessment' in the survey, resulted in a 'wish list' for the software tool [2]. The majority of SMEs stated that the software tool should focus on energy aspects and support them in fulfilling their legal requirements.

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These companies primarily want to communicate the energy consumption and self-declared environmental claims. Other requirements from the wish list were that the tool had to …

- be easy-to-use
- comply with the legal situation
- help improve product quality
- assess innovative products, without complete life cycle data sets
- be used as a kind of information platform to enhance the knowledge of the SMEs about LCA
- be able to import and/or export data

These requirements were integrated in the methodology and the design of the tool wherever possible.

To accompany the launch of the sector specific tool, companies were invited to participate in a free training and demonstration of the software tool. The incentives for them to take part in this training were to obtain a free assessment of their products and discuss the results and identify improvements together with external experts from the Vienna University of Technology.

3. Detailed description of the 'LCA to go' webtool

The basic software flow of the 'LCA to go' webtool for machine tools follows a two-step approach. It includes a rough assessment, followed by a detailed assessment where the user can focus on the most relevant life cycle phases. See Figure 1. The benefit of this approach is that, the first step; where the Cumulative Energy Demand (CED) over the entire life cycle is estimated; allows the user to identify the most relevant environmental hotspots very quickly, with minimal data requirements and the second step, allows the user to focus on these environmental hotspots to obtain a detailed environmental assessment. This detailed assessment paves the way to identifying targeted improvements and allows for a meaningful comparison of different machine tools. The methodology, basic software flow and application of the tool was kept very simple and transparent, while allowing the user to extract meaningful results for environmental communication.

The entire software tool was geared towards technical and development staff, with very limited time and without prior knowledge of environmental assessments or Life Cycle Thinking (LCT). To better serve the needs of the intended audience in SMEs, the software tool was translated and made available in six languages: English, Polish, Dutch, French, German and Spanish.

It contains ready-made datasets for the most widely used materials and common machine parts, extracted from ecoinvent 2.2 (May 2010). Since the tool should give a first impression of the environmental profile and not substitute a full and in-depth environmental assessment, the datasets are not being continuously updated, though this is possible in a later version of the webtool.

The tool is comprised of three major parts, Data entry (including Data Quality Indicators), Results (including a comparison function) and Improvements. These major parts are accessible from a home screen containing a list of all the modelled products and complemented by introductory texts.

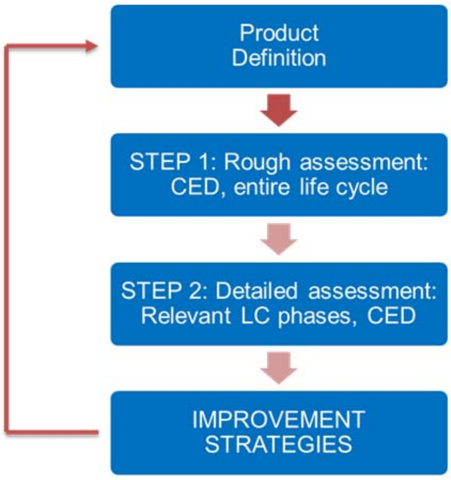


Figure 1 The basic software flow for the 'LCA to go' software for machine tools

The **Data entry** is again split into three different parts:

- General information such as the machine type, total weight and lifetime of the machine.
- Specific Data entry for the five different Life Cycle Phases (LCP), Materials, Manufacture, Distribution, Use and End of Life.
- Data Quality Indicators (DQI) which describe the source, reliability and robustness of the entered data in the five LCP.

The **Results** section is also split into three different parts:

- Detailed Results, showing an overview of the life cycle results in table form, together with the DQIs and the electrical power consumption in the 'Use' phase.
- Graphic Results, showing a graphical overview of the life cycle results as well as detailed graphical results for each LCP.
- Comparison, allowing the user to compare the results of two machine tools over the entire life cycle as well as specifically for each LCP.

The **Improvements** section offers general improvement measures, in line with ISO 14955-1 for fifteen different pre-defined subcomponents of machine tools.

3.1. Data entry for the five LCPs

To walk through the functionality and to demonstrate the results generated within the webtool, an exemplary grinding machine tool has been modelled. It weighs 20 tonnes, with a lifetime of 20 years and electrical power consumption of approximately 8 kW when 'Processing', 3 kW when 'Ready for operation' and 1 kW in 'Standby'. Additionally some compressed air consumption and the use of operating resources in the form of lubrication oil was assumed. Data entry in the rough and the detailed assessments follows the five LCPs displayed in Figure 2 below.

Figure 2 The five Life Cycle Phases (LCPs) for data entry in the 'LCA to go' webtool.

The data requirements in the five LCPs are minimal to reduce the administrative burden and ensure that the users can obtain a meaningful result without prior experience in environmental assessments. To facilitate data entry, the ‘Materials’ phase of the rough assessment for example allows the user to simply select from a list of eleven pre-defined supplier parts such as an electronic control unit, electric motor, worktool holder, oil mist extraction system, etc. The data entry in the ‘Use’ phase focusses only on the absolutely necessary pieces of information as shown in the screenshot in Figure 3 below.

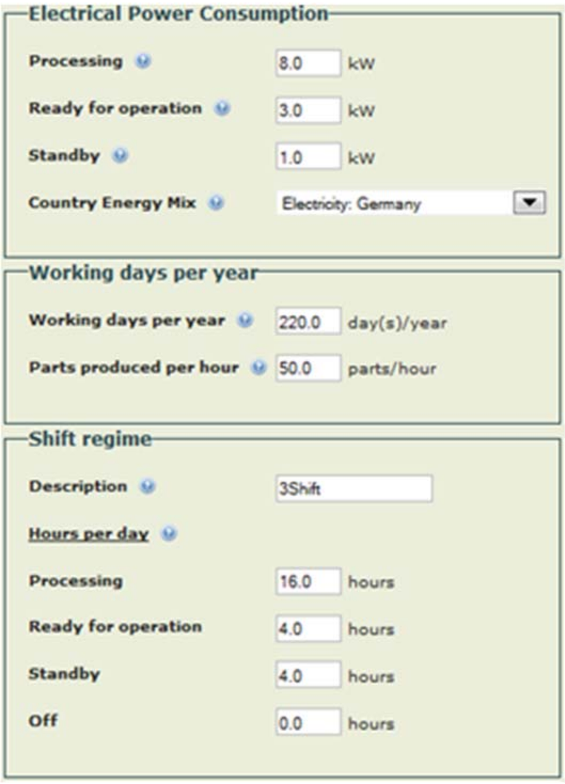
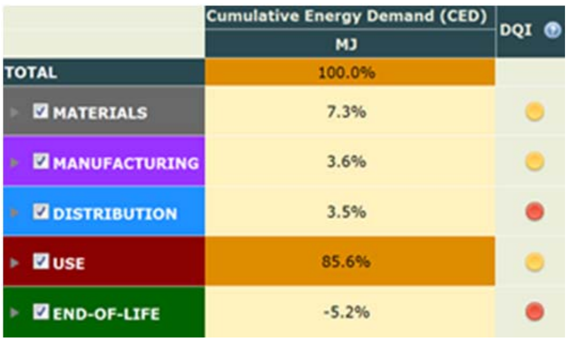


Figure 3 Data entry in the ‘Use’ phase of the rough assessment, requires only the energy consumption and the definition of a standard use scenario

3.2. Results

The quality and depth of the data as described by the DQI, can range from ‘Illustrative’ (red) to ‘Indicative’ (yellow) or ‘Robust’ (green) [1]. Prior to or in the course of the training, the rough assessment could be completed by the users in under twenty minutes. The results of this rough assessment are displayed as shown in the screenshot in Figure 4 below.

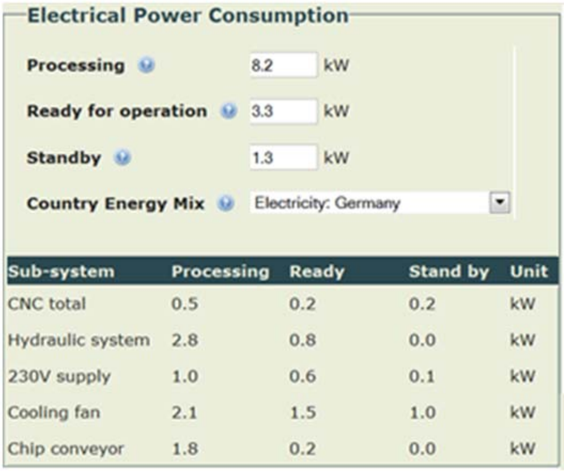


	Cumulative Energy Demand (CED) MJ	DQI
TOTAL	100.0%	
MATERIALS	7.3%	(yellow)
MANUFACTURING	3.6%	(yellow)
DISTRIBUTION	3.5%	(red)
USE	85.6%	(yellow)
END-OF-LIFE	-5.2%	(red)

Figure 4 Table of Life Cycle results generated in the rough assessment.

As can clearly be seen, the user can quickly and easily generate a result which identifies the most relevant environmental hotspots and describes the associated quality of entered data for the key LCPs. In a second step, the user, now familiar with the webtool, can collect and enter more detailed and robust data for the most relevant LCPs. In this specific example, the dominant ‘Use’ phase and the ‘Materials’ phase are examined in more detail.

The data entry in the detailed assessment covers the same five LCPs (Figure 2), however allows for the entry of much more detailed data. In the ‘Use’ phase additional energy flows such as compressed air and the use of process consumables such as gases and lubrication oil can be included. It also allows for the definition of up to three ‘Use’ scenarios and the assignment of the electrical power consumption to different machine sub-system as shown in Figure 5 below.

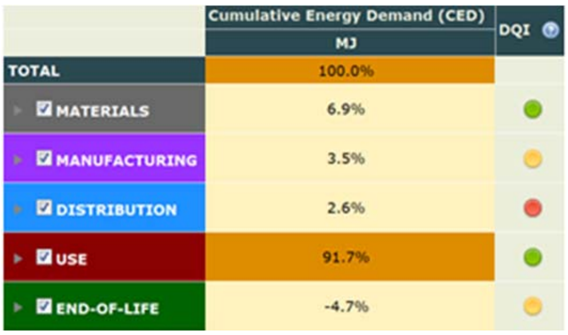


Sub-system	Processing	Ready	Stand by	Unit
CNC total	0.5	0.2	0.2	kW
Hydraulic system	2.8	0.8	0.0	kW
230V supply	1.0	0.6	0.1	kW
Cooling fan	2.1	1.5	1.0	kW
Chip conveyor	1.8	0.2	0.0	kW

Figure 5 Data entry in the Use phase in the detailed assessment in the ‘LCA to go’ software tool

Having collected and entered more data for the two most relevant LCPs, ‘Materials’ and ‘Use’,

Figure 6 shows the increased robustness in the quality of the underlying data and a small shift in the overall distribution of the environmental hotspots. The overall distribution over the entire life cycle does not change drastically due to this more in depth data.



	Cumulative Energy Demand (CED) MJ	DQI
TOTAL	100.0%	
MATERIALS	6.9%	(green)
MANUFACTURING	3.5%	(yellow)
DISTRIBUTION	2.6%	(red)
USE	91.7%	(green)
END-OF-LIFE	-4.7%	(yellow)

Figure 6 Table of Life Cycle results generated in the detailed assessment.

This general outcome was replicated in all the case studies and validates the two step approach, meaning that if a user simply wants to derive the environmental profile and the most relevant LCP the rough assessment will provide a first result, sufficient for this purpose. The detailed result then permits the user to investigate in much greater detail the source of the

CED in each LCP, obtain more reliable results, allowing for a better communication with the customer. It also enables the user to identify improvement measures and compare machines.

For the ‘Use’ phase in the detailed assessment for example, the CED is displayed by operating state (‘Processing’, ‘Ready for operation’, ‘Standby’), allowing the user to identify the most important operating state in different use scenarios. This enables the user to derive which operating state offers the highest improvement potential and whether software changes, such as the integration of a “Sleep mode” could bring significant reductions in the environmental impacts. Further, the user has the opportunity to identify the most relevant machine sub-systems in the ‘Use phase’ as shown in Figure 7 below.

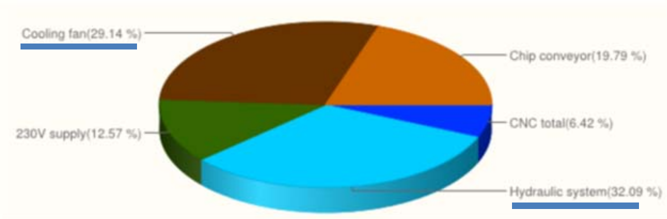


Figure 7 CED in the Use phase given for the different machine sub-systems

This result can then be used to derive sub-system specific improvement measures contained in the webtool.

3.3. Improvements

The detailed results for the ‘Use’ phase shown in Figure 7 can be used to derive improvement measures for these sub-systems in the ‘Improvements’ section of the tool. In line with ISO 14955-1, improvement measures for the following sub-systems are predefined in the ‘LCA to go’ tool.

- General
- 24V supply
- 230V supply
- Air compressor
- Chip conveyor
- CNC air-conditioning
- CNC total
- Cooling fan
- E-R module supply
- Fan ER module
- Fluid system
- Hydraulic system
- Mist collector
- Monitoring module
- Spindle cooling pump

The list of individual improvement measures for each sub-system contains concrete suggestions. An example of one such measure for cooling devices is given in Figure 8 below.

> *“Thermal management of machine tool and all components (e.g. cooling devices,...): Optimized concept for thermal management of all machine tool components regarding:*
>
> 1. *Minimization of thermal power losses;*
> 2. *If thermal power loss is not avoidable, it has to be dissipated by air or water cooling; for reuse of thermal energy water is given a preference compared to air; further reuse of thermal energy has to be checked/discussed with customer (e.g. via standardized interface);*
> 3. *Controlled ventilation (fan).*” [3]

Figure 8 Example of a concrete improvement measure available in the ‘LCA to go’ webtool and taken from ISO 14955-1

Following the detailed assessment and improvements to the machine tool, the ‘LCA to go’ tool offers the possibility to compare two machines either in individual LCPs or over the entire life cycle. This feature can be used to identify improvement potentials in the design phase or to compare and communicate achieved improvements in finished machines.

4. Case studies

The software tool was applied together with 16 case study companies to model their products. The companies were then interviewed regarding motivations for the assessment, their experience with the tool, the most interesting results and their further plans to work with the tool. The results of these interviews are compiled in this section.

The investigated machines included machine tools such as Grinding and Milling machines, Transfer centres, Electro Discharge Machines and Complete processing machines as well as other industrial machines such as robots, surface treatment machines, compressors, conveyors and storage centres. This wide range of industrial machines and machine tools demonstrates the broad scope of the software tool and its broad scope.

The 16 participating SMEs in Austria, Belgium, Germany, Switzerland and the UK gathered the required data and worked together with the authors in applying the tool, generate and analyze the results and identify possible improvement measures. For each company, this entire process, from collecting data to analyzing results and collecting feedback took on average 6 working hours over a period of a few weeks, including a company visit in half of the cases and was documented in the form of individual case studies available at www.lca2go.eu/sectors,tooling.en.html

4.1. Previous experience with LCA or Ecodesign

While 75% of the interviewed companies indicated to specifically be focusing efforts on improving the energy efficiency of their industrial machines, only 19% of the participating companies had previous experience in taking a Life Cycle approach to development and design. This means, environmental considerations are not a major topic for material choices, production technologies or end of life issues for most of the interviewed companies.

4.2. Motivations for an environmental assessment

Companies were allowed to provide multiple answers regarding the motivating factors. There were five different major motivations for companies to carry out an assessment of their machines. Most (7) companies indicated that they applied the tool as part of their continuous improvement process, looking for innovative ways to further develop their product. (6) companies indicated that the reason for applying the tool was to take a proactive approach regarding upcoming legislation and standardization. (5) companies were also motivated by the chance to better understand the energy consumption of their product and the environmental impact over the entire Life Cycle. (3) companies indicated that they wanted to communicate the results to customers while (3) companies expected the tool to allow a comparison among competitors. One of these three companies would have liked to see a database with assessments of other machines for comparison included in the tool.

4.3. Interesting or surprising results

All investigated industrial machines were found to be Use intensive products. For most companies, this was the first Life Cycle look at their machines and most (8) companies found the dominance and the detailed results in the Use phase particularly surprising or interesting. (3) companies who were already expecting the clear dominance of the Use phase were most interested in identifying the specific improvement areas and sub-systems in the use phase. (2) Companies found the Life Cycle perspective on their machine tools as primarily interesting. (1) company described the validation of the ongoing research effort as the most interesting result while another (1) company described the relative importance of the electric and electronic components in the 'Materials' phase as particularly surprising, especially since these components make up only a small part of the total machine mass.

4.4. User experience and further use of the tool

Most companies (11) indicated that they will use the tool to support their continuous research and development and to investigate specific improvements. (3) companies will communicate the result to their customers and use it to fulfil customer requirements. (2) companies indicated that they will use the tool to compare different products while (2) further companies indicated to be working on their own software internally.

4.5. Advantages for the companies through the use of the tool

In the interviews, companies were also asked to identify advantages through the use of the tool. They have been grouped in the list below.

4.5.1. Standardised characterization and documentation

- Standardised documentation of progress in minimising environmental impacts
- Characterisation of machine from environmental standpoint

4.5.2. Easy communication

- Can easily comunicate the advantages of their product over the entire life cycle, especially in the Use phase.
- Can easily comunicate the result and improvements to customers

4.5.3. New development perspective

- Detailed identification of environmental hotspots
- Life Cycle view of the machine opens new development perspective
- Findings spill over to the entire product portfolio
- Improving the energy efficiency of a machine tool will improve the environmental impact and profitability of the final product. Justification of further research into the use of energy and process consumables

4.5.4. Own tool development

- Basis for own development

5. Barriers and Limitations

The trainings went a long way in dispelling the common barriers for SMEs to carry out environmental assessments of their machines. The user friendliness and clear structure of the data entry and the results went a long way in facilitating the application of the tool and enabled the training.

5.1. Three major barriers to the application of the tool

Most companies cited time and resource constraints as the main barrier to participating in a training or applying the tool. Getting companies to understand the data needs and believe the limited time requirements to carry out a first assessment was a challenge. To overcome this challenge, the companies were asked to fill a very short and simple excel sheet with some basic data in preparation for training. This data was entered into the tool either before or during the training. A first assessment was therefore possible in around 15 minutes and without the need for the companies to register for the tool beforehand. This impressed the companies and got them interested in further assessments. However, getting them to believe that a training (entering data, generating results, identifying improvements, comparing products) could be done in approximately one to two hours remained a hard sell, as their experience with these types of tools was that they require a lot of time.

The second barrier was to get the SMEs to understand the benefits of applying the tool. They often asked which immediate benefit they would obtain? Will they sell more machines with this tool? To overcome this barrier, a list of direct benefits was created and tailored for each company. The four major advantages were listed as:

- taking a proactive approach to upcoming legislation;
- analysis of the machine tool from a different standpoint to identify improvements;
- communication of results;
- detailed assessment of the 'Use' phase in different scenarios.

In some cases this helped to convince companies to participate, in others, companies still did not see the direct benefit and therefore did not partake. This barrier will likely only be removed if the tool was used for standardized reporting to fulfil legal requirements or customers begin to demand this type of information.

A third barrier was that companies often have a clear set strategy for development and do not want to create ‘extra work’ by diverting from this strategy, which in most cases focuses on energy efficiency in workpiece processing rather than the LC.

5.2. Limitations of the tool

Companies also cited three major limitations of the tool.

Some companies would have liked to see a tool, even more tailored to their specific product and cited the broad approach as a limitation. This ‘limitation’ was in fact praised by other companies, who were surprised that a tool designed specifically for industrial machines was so adaptable and could be applied to the wide variety of different machine tools under investigation.

One company would have wished for a central database containing results of the machine tool market. This database would enable companies to directly compare their machines to competitors or the market average. This would however require the release of sensitive data by the companies and can therefore not be easily implemented.

Companies would have liked to see the introduction of an Energy Efficiency Index or an Energy Label. The complexity of the market and the great variety of machines, production volumes and finishing qualities makes this task very difficult. Machine tools are already the focus of different initiatives which have not been successful thus far or are not applied widely. The European Commission’s attempt to cover the machine tools by the Ecodesign Directive resulted in a Self-Regulation Initiative [4], which is under discussion since 2009. In parallel, the ISO 14955 [3] on the environmental assessment of machine tools or a method to measure the energy usage and to calculate an Energy Efficiency Index by the German Society on Numeric Control (NCG) [5] has been developed but not yet applied.

6. Conclusion

6.1. Lessons learnt in the application of the tool

Through the training and application of the webtool together with the companies, the software proved that it can be applied to wide variety of different industrial machines such as Electro-Discharge machines, milling machines, storage systems, etc.

The application also validated the two step approach, which was greatly appreciated by the companies: The rough assessment provided a very quick, but overall representative, environmental profile, which helped create awareness and determine the hot spots. The detailed assessment of the relevant hotspots provided in depth results and allowed for the identification of specific improvement measures and for the comparison of two machine tools.

6.2. Companies’ experience and feedback

Energy efficiency is becoming an increasingly important topic for machine tool producers and entering into purchasing decisions for their customers. Environmental assessments, Life Cycle Thinking and Ecodesign are relatively new to this industry but companies (especially lager companies) are recognizing advantages to adopting these concepts. The trainings showed that, especially companies that had already improved their machine tool environmentally, were keen on using the tool to verify their assumptions and obtain quantified results, to communicate with their customers. For others the training raised awareness and identified or validated key research areas to improve their products. Especially the Life Cycle perspective, with details for the ‘Materials’ and ‘Use’ phases, the possibility to compare two products and the inclusion of improvement measures offers companies a different view in their research and development efforts. The SMEs appreciated the sector specific tool which provides information in a way that can be directly communicated to the customer.

Companies are anticipating legislative developments in this area and want to take a proactive approach. They indicated that they intend to continue using the tool to support their development efforts, identify and evaluate improvements and communicate with their customers.

6.3. Further possible developments

The tool could still be expanded and improved in two concrete ways. One would be the development and inclusion of a database with results from across the market. This idea would require a totally different approach from the data storage side, which in turn might reduce the number of participating companies due to concerns over data security. The existing webtool offers a first step in this direction but deliberately stops short of trying to provide a comparison across the sector to provide data security and privacy. The second idea would be the expansion of the ‘Use’ phase to incorporate further indicators which might facilitate the development of an Energy Efficiency Index or Energy Label for machine tools.

Both these ideas would need to be accompanied by stringent measurement standards, information on the quality of the produced parts and concrete lifetime information for the machines.

In general this describes just the perspective of SMEs in this sector, larger companies are a bit further in considering environmental aspects in product development e.g. knowing the energy consumption of their machines in detail and focusing on energy efficient products, while life cycle thinking is not yet integrated and only applied in single projects.

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