Comments from ECOS on the draft Ecodesign preparatory study on Machine Tools (lot ENTR 5)

17 May 2011

Background

ECOS has provided comments on the draft tasks 1, 2 and 3 of the study in November 2010. The comments here cover tasks 4 and 5.

Most of the comments are based on the experience and results achieved by researchers from INEGI (Instituto de Engenharia Mecanica e Gestao Industrial in Portugal) appointed by ECOS to contribute to the preparatory study. These experts have been working on machine tools in the framework of internal projects related to the ecodesign of machine-tools (MT), which resulted in a set of scientific papers available for public consultation [Azevedo 2011, Oliveira 2011, Pereira 2010, Santos 2010]. From this, and supported by the results of others, it can be concluded that the most significant environmental impacts of a machine tool are mainly affected by 3 types of factors:

- The full set of resources used to obtain the machine 'as-is', accounted as input-output substances associated to the component production and assembly stage of the MT (materials and manufacturing processes-related);
- The electricity consumption required by the MT during operation, accounted as the specific process energy (SPE) related to the main functionality of the machine during its use stage;
- Other process- or operation-related resources, apart from electricity, accounted as input-output substances associated to the use stage of the MT (consumed directly in the process, by the auxiliary systems during operation or in maintenance operations).

In addition, INEGI experience regarding LCA methodologies and the contacts with other groups working in this field also contributed to these ECOS comments.

Overview and comments on draft Task 4 'Assessment of base cases'

Table 1 presents the positioning of the base cases regarding the 3 main factors mentioned above.

Base-case	Main Environmental Impact (EI) Contributors		
	Production+Assembly	Use-Energy	Other Use-Consumables
1- CNC milling and turning MT	Overall analysis Aggregated BOM from 9 MTs (CECIMO)+1 CNC milling center	SPE from production scenario described for the CNC milling center adopted Lifetime = 12 yrs	Tools (postponed) Hydraulic oil, lube oil, cooling fluid and lubrication emulsion (referred) Water (accounted)
2- Hydraulic Press-Brake	Overall and sub-system level analysis	Overall SPE value based on ref. production scenario, but real scenarios models are available Lifetime = 17 yrs	Tools (postponed) and Hydraulic oil (data provided) are referred but not accounted
3- Non-CNC metal working MT	(ongoing; stakeholders addressed) Overall analysis	(ongoing; stakeholders addressed)	(ongoing; stakeholders addressed)
4- Wood working MT	(ongoing; stakeholders addressed) Overall analysis	(ongoing; stakeholders addressed)	(ongoing; stakeholders addressed)
5- Welding equipment	(ongoing; EWA addressed) Sub-system analysis	(ongoing; EWA and members addressed)	(ongoing; EWA and members addressed) Gas and wire are referred
6- Other MTs and related machinery	(open)	(open)	(open)

Table 1 – Conditions used in the assessment of the Base-Cases selected, regarding the main contributors to the environmental impact of machine-tools

The data collected until this stage appears limited, and mostly there seems to be still room for improvement on the Base Case selection and assessment methodology to adopt.

Base-Case 2 results were provided by INEGI. Real SPE results obtained from a comparative analysis between press-brakes technologies and usage modes are also available. Similar comparative studies have been followed for Laser cutting machines. These studies suggest that:

- Technology should be used as a Base-Case selection criterion for such MT investigations, as it determines all the set-up regarding the 3 types of detrimental factors to the environmental profile of the machines. Hydraulic and all-electric press-brakes, as well as CO_2-laser and Fiber Laser cutters, have been compared regarding SPE, but quite interesting results should be expected from other machine-groups, such as welding equipments, and in the other contributing categories such as the non-energy-related consumables during use stage. Among the Base-Cases used, this criteria is only clear for the press-brake (hydraulic), as for metal working machines only CNC (Base-Case 1, milling and turning only) and non-CNC (Base Case 3) are distinguished, while for the other Base Cases this is totally lacking. Note that a press-brake is also a metal working machine which could fit in the Base-Case 3 generic category.

- The discussion on the overall *vs* sub-systemic (energy-consuming or not) approach still seems to be relevant. On the one hand, while in the standard heavy-weight machines the massive structure dominates the machine assembly contribution, the trend to more efficient power technologies, modular design, electronic and electromagnetic components (particularly non-ferrous metals, such as the detrimental Cu) and structural light weight materials might justify the sub-system approach. On the SPE side this approach, covering the energy-consuming sub-systems only, is definitely the one to adopt targeting the identification of main contributors, even if the total SPE value is the one to be finally accounted in the MT ranking as followed for the production stage's input. Although for Base-Case 2 this was not followed, this was the approach used on the later Laser cutter study, and the benefits for the identification of main energy-consuming factors became evident.

Besides, it must be noted that as the Base-Case data was provided by different sources, different data collection and accounting methods have been used, i.e., results are not comparable and the individual contributions are determined by the methodologies used. (Moreover, the limitations of the non-standardized MEEuP methodology and their impact on the assessment results were previously addressed in a separate letter.)

Overview and comments on draft Task 5 'Technical Analysis'

The draft is an interesting document supporting the discussion on improvement potential and presenting several technical solutions for the main factors contributing to the environmental impact of MTs, mainly energy-related but not-only. The technical analysis followed presents solutions for the 3 types of factors listed above, namely the assembly resources (S1, S5), the energy consumption during use (S2, S3, S4, S5, S7, S9) and the other consumables related to machine operation (S6, S7). Besides, several important comments regarding technological and market trends, sector future needs and other relevant topics to consider for MTs are included and support an integrated perspective of the proposals. Among these, references to the need of combination of measures, productivity and functionality as conditions of application, cost implications of the individual measures/options, operating modes, configurations of process parameters, maintenance needs and process chain shortening are to be highlighted.

Some of the sub-systems and solutions had also been included in the previous voluntary initiative (SRI) proposed by CECIMO/PE-International in 2009, which participation here is properly referred to. The statement that the BAT/BNAT approach (also advanced in the SRI proposal) for MTs should be followed on the individual component/sub-system level seems reasonable. Here, CECIMO SRI goes even further by weighing the sub-systems contributions and this could be discussed.

The role of the technology choice

In the Introduction section (end of page 7), the importance of the 'proper technology choice' is mentioned as being determinant to the environmental profile of a MT for a specific manufacturing task, as well as its potential for improving environmental aspects. However, this was considered not a design issue and, in the framework of the components level BAT approach, this was not further developed. As explained above, Technology is considered most relevant as categorization criterion for MT grouping, environmental assessment, SPE analysis and any other environmental performance related aspects. This categorization is even obviously implicit in such a sub-system BAT analysis, although this is based on energy-efficiency targets only. Thus, the option of omitting MT Technology as an optimization criterion is not fully understood, in the sense that pushing for the Best Available Technologies for a specific manufacturing task/application could trigger substantial environmental benefits.

The full implications of technology selection to the environmental profile of the machine on the contributing factors have to be better analysed, and not only for the energy consumption during the

use stage of the machine. Particularly on the production stage level, and for the sub-system approach, it was also demonstrated by INEGI [Pereira 2010] that '*even small volume components may have significant contributions and result in huge differences on the environmental impact indicators, as those observed for a shaft bushing when changing from a non-ferrous material to a 50-50%wt (~80-20%vol) steel-graphite composite, when compared to the ferrous-based components. While the significant impact of the housing material was more evident from the volumetric contribution of the component, the determinant impact of such a small volume component could be missed.*' Furthermore, the trend for all electronic or electromagnetic versions should push for more complete LCA analysis, as this includes additional electrical and electronic components, which typically include an higher amount of hazardous materials [Santos 2011] as referred for Base-Case 2.
On the use stage, it is important to highlight the interesting work followed by the CO_2PE initiative [1], which has been working on the definition of a methodology for systematic analysis and improvement of manufacturing unit process life cycle inventory (UPLCI), i.e. on the deep analysis and quantification of the environmental impacts of manufacturing processes. As resumed in their last report [Kellens 2010], this methodology '*comprises two approaches with different levels of detail: the screening approach and the in-depth approach. The screening approach relies on representative general data and theoretical calculations for energy use, material loss, and identification of variables for improvement. The in-depth approach is subdivided into four modules, including a time study, a power consumption study, a consumables study and an emissions study, in which all relevant process in- and outputs are measured and analyzed in detail. To ensure optimal reproducibility and applicability, documentation guidelines for data and metadata are included in both approaches. Guidance on definition of functional unit and reference flow as well as on determination of system boundaries specifies the generic goal and scope definition requirements of ISO 14040 and ISO 14044*'. Developed with the purpose of providing high-quality life-cycle inventory (LCI) data for manufacturing unit processes, this work seems also to fit the needs of methodology standardization for the MT use stage analysis in this preparatory study and subsequent work.

As discussed in several forums, the definition of a standard job to use for comparative studies of relevant technologies available, and for pre-defined application ranges (material, shape, process quality,…) is required. Relevant technologies and application ranges should be selected from the manufacturers or their associations, considering the respective technology/application market shares.

Mass reduction of moving parts

The issue of the cost of alternative materials and the technical mastery on the MT manufacturer side is important, although this can be seen as a positive factor pushing for new dynamics to the sector.

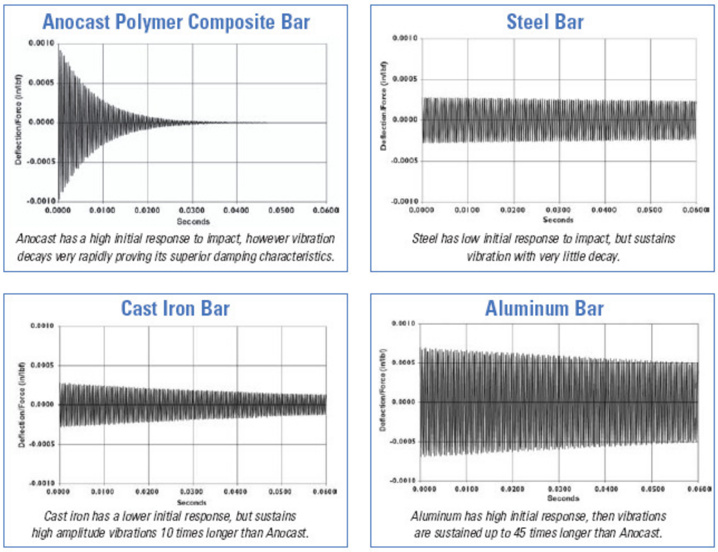
The achievements of the ECO-fit project on the replacement of main materials is referred and described later (section 5.1.11.3) in more details. Although the validation of the total life-cycle benefits is mentioned, the introduction of reinforced polymer based composites or light-weight metals should be carefully analyzed, particularly regarding the lifetime and end-of-life disposition of such components/materials (although a lot of work is going on regarding innovative end-of-life strategies for these materials, which should be closely followed).

Still on this topic, INEGI has been involved in a project focusing on the replacement of the steel welded MT main structure by an innovative polymer concrete solution (also referred as 'mineral casting'). Although this indirectly contributes to both measures proposed (i.e. replacement of current materials by lightweight alternatives and general material reduction), the introduction of high-performance materials should be considered as an additional measure considering its significant environmental, technical and cost impacts. The potential use of polymer concrete and its advantages are mentioned in a later stage of the task report (BNAT section 5.2.3) regarding solutions for modularisation, versatility and optimisation of energy consumption. This solution is seen to satisfy and overcome the static and dynamic stiffness and vibration damping requirements also referred to in this section. The environmental and cost impacts of this alternative was analysed in a preliminary study by the MT manufacturer involved in the project (Figueira 2010). Part of the report on this is presented below.

Steel *vs* polymer concrete: market opportunities and environmental aspects

Steel pricing is undergoing a revolution as prices rise. The change in steel pricing policy and current steel cost indicate that current overheads will be directly affected, and some MT manufacturers have already raised their prices. Although the need for alternative materials, less subjected to such market variations, became more evident, this is a complex task as MTs often have specific requirements for high stiffness, dimensional stability, ease of manufacturing, good dampening properties and high mass to avoid rigid body movements. If any of these features is not met, process quality might be compromised.

Several studies have been conducted in order to find alternatives to welded steel structures dominating in MT production. Here, polymer concrete structures appear as a promising alternative due to several technical advantages: better dampening, non or less machining requirements, lower lead times, capability to integrate functions due to moulding process and low heat conductivity allowing for better overall dimensional stability, ideal for precision machines. Currently, polymer concrete shows a versatile application within the range of tooling machines, measuring technique, machine racks, energy machines as well as machine parts.



Anocast Polymer Composite Bar

Anocast has a high initial response to impact, however vibration decays very rapidly proving its superior damping characteristics.

Steel Bar

Steel has low initial response to impact, but sustains vibration with very little decay.

Cast Iron Bar

Cast iron has a lower initial response, but sustains high amplitude vibrations 10 times longer than Anocast.

Aluminum Bar

Aluminum has high initial response, then vibrations are sustained up to 45 times longer than Anocast.

Figure 1 - Material comparison regarding vibration dampening (based on Anocast solution [2] data).

Polymer concrete is produced with mineral aggregates, which are crushed to meet specific grain size, then washed and dried, before mixing with an epoxy resin at ambient temperature. Resin degassing and vibratory compaction during the moulding process allow for a more homogeneous, compact and air pocket free casting. There are several recipes for epoxy polymer concrete, each one with different properties and customized for specific applications.

Table 2 compares polymer concrete against cast iron and steel welded base, including the initial energy consumption impacts. As it can be seen, polymer concrete presents several advantages over conventional metal structures.

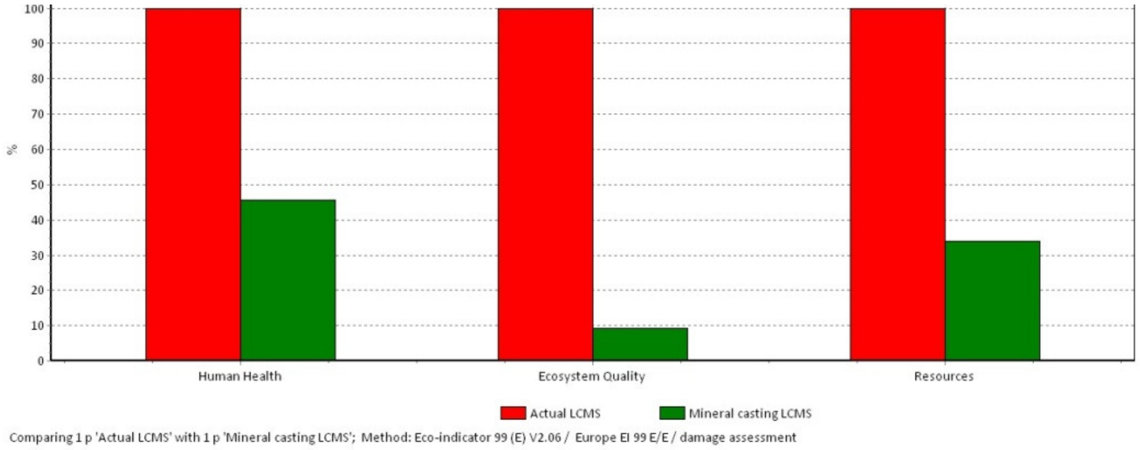
Criteria	**Cast Iron**	**Welded Base**	**Mineral casting**
Stiffness	High	Very high	**Very high**
Dampening	Medium	Low	**High**
Thermal stability	Fast reaction	Fast reaction	**Slow reaction**
Design freedom	Restricted	Less restricted	**No restrictions**
Surface quality	Low	Medium	**High**
Re-build	**Good**	**Good**	Possible
Lead time	Medium	Very long	**Short**
Environmental aspects	High initial energy consumption to build	High initial energy consumption to build	**Low initial energy consumption**

Table 2 - Process comparison for 3 different structural materials available for machine-tools.

The environmental aspects to be looked at include:

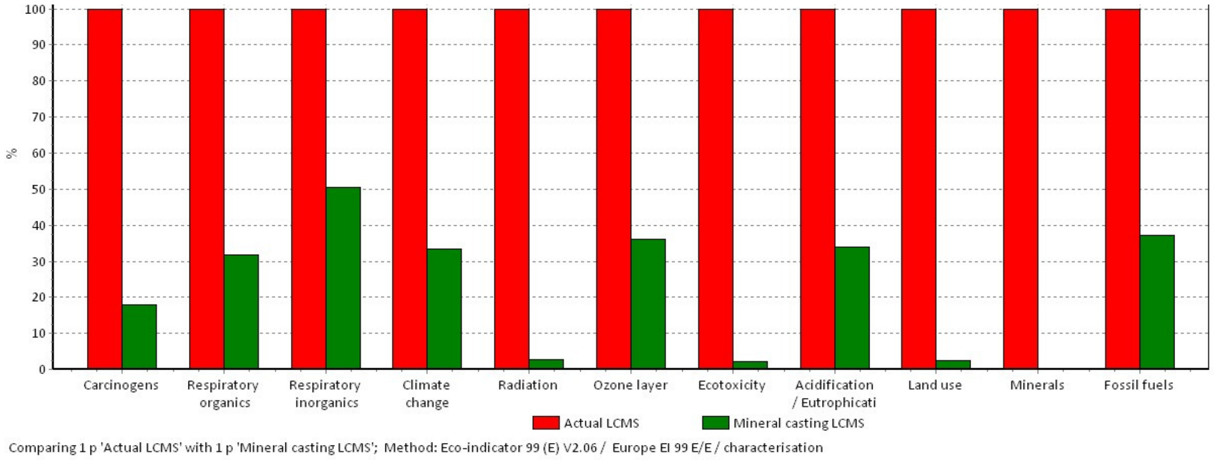
- Embedded Energy: The energy requirements to produce a polymer concrete structure is previewed as about 25% of that needed to produce an equivalent welded steel structure.
- Process steps/Production time reduction: Since mineral casted structures can be produced in a single-step, they are substantially faster available than traditional casting or steel welded parts. Normally the curing process can take up to 24 h. The cold casting process has no need for additional heat introduction, thus allowing saving energy.
- Lifetime/Chemical Resistance: Polymer concrete is chemically inert against aggressive materials such as oils, caustic solutions, acids and liquid-coolants.
- Recyclability: It can be deposited and potentially recycled. If crushed it can be re-used as a mineral casting filler.

Results of an LCA study followed (based on Eco-Indicator99) for comparison of the current steel welded structure and the polymer concrete alternative are presented in figure 2, and clearly confirm that polymer concrete MT are a more eco-friendly solution than the current welded-steel solution.



Comparing 1 p 'Actual LCMS' with 1 p 'Mineral casting LCMS'; Method: Eco-indicator 99 (E) V2.06 / Europe EI 99 E/E / damage assessment

(a)



Comparing 1 p 'Actual LCMS' with 1 p 'Mineral casting LCMS'; Method: Eco-indicator 99 (E) V2.06 / Europe EI 99 E/E / characterisation

(b)

Figure 2: LCA results of the comparison between machines with steel welded and polymer concrete (mineral casting) structures per: (a) end-point and (b) middle-point environmental impact categories

Potential limitations to the use of polymer concrete include:

- Resistance to flaming combustion: Direct incidence of the thermal beams into the structure should be avoided.
- Shrinkage: Might represent a problem in thick bodies; high contraction leads to internal cracking appearance.
- Extra thermal processes: Although curing typically takes place at room temperature, some resin systems are heat treated for added strength and stability.
- Raw-material Cost: Aggregates exist in abundance and there are several companies which can supply mineral products where composition, granulometry and quality are certified. Unfortunately they represent less than 1% of the cost, although they are about 90% of the weight. There are some ready to use grout in the market. These products have the advantage of being market proven, allowing to reduce risk and time-to-market; the drawback is their higher cost. Resins cost represents approximately 84% of the final cost. In general, epoxy resins are about four times more expensive than polyester resins. Depending on the quality requirements, polyester could be a preferable choice.

Role of the MT user in energy management options

Although widely discussed in different areas, this is a topic that MT end-users tend to neglect, as confirmed in many of the questionnaires where INEGI was involved. The importance of enabling ’the user to provide detailed insights into the energy consumption of the production process’ is essential to accomplish the optimization of the MT environmental profile during the use stage, as the user is most actively involved in this process. Independently of the many possible solutions targeting the control of the MT, the user’s insight is surely determinant for this optimization. Further parallel actions on this should be encouraged.

Regarding the stand-by management discussion, it is important to highlight the importance of the overall approach besides the sub-system approach. As concluded from the Laser cutter study, although the sub-system dimensioning and energy-consumption could be individually optimized for a specific application condition range, these are quite technology dependent. Besides, considering that MTs typically operate in very distinct operating modes, it is important to ensure that all sub-systems are properly synchronized in each operating condition and the respective power consumption profiles should be matched. This is expected to contribute significantly for the reduction of the power demand and improved efficiency of auxiliary main-systems against the main energy source sub-system, as shown.

Best non-available technologies (BNAT)

The BNAT section consists in the presentation of a wide set of on-going projects running in Germany. The reference to the NEXT and PROLIMA EU projects is highly appreciated, although the compilation presented in the CECIMO’s draft SRI should also be referred to. The solutions proposed in these compilations would also fit perfectly as BAT identification sources.

Conclusion

At this stage, the work led by Fraunhofer IZW to draft the preparatory study resulted in a quite extended and detailed overview of the improvement potential of the environmental profile of machine tools. The compilation of data and projects running on this subject shows the high interest and efforts devoted by the European MT manufacturers and their associations, research institutes and academia on finding added-value and effective solutions, which is essential for the success, sustainability and continuous improvement of the Ecodesign measure to be adopted.

Regarding the environmental profile definition and classification, the main factors seem to have been identified, however the environmental assessment methodology and machine tool categorization still requires improvement and fine-tuning. To accomplish this more effectively, consideration of the experience and results of other parallel research teams is suggested, such as the CO_2PE! initiative on the environmental characterization methodology of manufacturing processes. In addition, the on-going preparation of the revision of the MEEuP methodology could also contribute to improving this categorization-characterization-improvement strategy, and should be closely followed. This is essential for the proper assessment of any characterization result and for the future development of key-performance indicators, classification system or any other standards.

Contacts

Expert at INEGI:

Ana Rosanete Lourenço Reis
(Professor Auxiliar)
FEUP - Faculdade de Engenharia da Universidade do Porto
E-mail: arlr@fe.up.pt

Desk officer at ECOS:

Edouard Toulouse
Ecodesign Officer
ECOS (European Environmental Citizens' Organisation for Standardisation)
E-mail: edouard.toulouse@ecostandard.org

References

Azevedo M., Oliveira M. I., Pereira J.P. and Reis A., "Comparison of two LCA Methodologies in the Machine-tools Environmental Performance Improvement Process", 18th CIRP International Conference on Life Cycle Engineering, Braunschweig-Germany, Mai 02-04, 2011

Figueira J., Local manufacturer internal viability study of polymer concrete for machine-tools (2010).

Kellens K., Dewulf W., Overcash M., Hauschild M., Duflou J. R.,"Methodology for systematic analysis and improvement of manufacturing unit process life cycle inventory (UPLCI)", Paper submitted for publication in the International Journal of Life Cycle Assessment (2010)

Oliveira M. I., Santos J. P., Almeida F. G., Reis A., Pereira J.P. and Rocha A. B., "Impact of Laser-based Technologies in the Energy-Consumption of Metal Cutters: Comparison between commercially available System", 14th International Conference on Sheet Metal, Leuven-Belgium, Apr. 18-20, 2011, Key Engineering Materials Vol. 473 (2011) pp 809-815, Trans Tech Publications, Switzerland, DOI:10.4028/www.scientific.net/KEM.473.809

Pereira J. P., Reis A.; Oliveira M. I., Rocha A. B., "Modeling of Mechanical Systems for Environmental Impact Assessment in Design Stage", Paper submitted for publication in the International Journal of Life Cycle Assessment (2010).

Santos J. P., Oliveira M. I., Almeida F. G., Reis A., Pereira J.P. and Rocha A. B., "Improving the environmental performance of machine-tools: influence of technology and throughput on the electrical energy consumption of a press-brake", Journal of of Cleaner Production, Volume 19, Issue 4, March 2011, Pages 356-364, DOI: 10.1016/j.jclepro.2010.10.009

[1] www.mech.kuleuven.be/co2pe!/index.php
[2] http://www.rockwellautomation.com/anorad/downloads/pdf/Anocast.pdf