Technical assistance study for the assessment of the feasibility of using "points system" methods in the implementation of Ecodesign Directive (2009/125/EC)

TASK 4
Machine Tools Case Study

Draft report v1

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Methodological concept for a point system in the case of machine tools

After defining a generic Ecodesign points-system for complex products in Task 3, this case study applies this methodology to machine tools. The methodology is set out in the same steps that are described in the Task 3 report, but is applied to the specific use case of machine tools. Readers should note that the example given here, especially when considering Steps 7 to 9, is applied to a hypothetical type of machine tool in order to test the proof of concept. It is not intended to represent any specific category of machine tool nor are the values used intended to be representative of actual machine tool values (although the type of design options and configurations used are common to typical products).

This case study has been confined to addressing energy performance in the use phase because this is already a major challenge for machine tools and is the dominant environmental impact; however, it is certainly conceivable that other environmental impacts could be treated using this, or a similar methodology.

The Task 3 methodology has been tested in this case study for the energy performance of machine tools and in principle it has been established that the method:

- Seems to be suitable to assess energy performance
- enables complexity to be addressed
- recognises and rewards good ecodesign practice
- is designed to award points for design options in proportion to their expected effect on the impact parameter in question
- is as comprehensive and inclusive as possible and allows the option to extend the scheme's structure to include: the environmental impacts deemed appropriate (energy performance in this case), the product scope that is deemed most appropriate, the intervention phases deemed appropriate
- is capable not only of working at whatever application grouping levels are deemed to be appropriate but even for unique customised machine tool designs
- is adapted to address product modularity
- fits within the MEErP methodology, although it does not require some of the steps, and additionally does require detailed information on expected savings from using specific design options at the module level
- is capable of working with the Ecodesign and energy labelling regulatory process
- is technically feasible from a conformity assessment perspective, but will require a more elaborate procedure than is the case for simpler products.

Step 1 Assessment of key lifecycle stages

This step involves the assessment of the key life cycle stages of the product in question. The intention is not only to develop a points-system to assess the components of a complex product but also to integrate this methodology into the ecodesign development process and ecodesign thinking. Therefore, environmental aspects should also be considered in the design and development process as well as in the use phase. The schematic below illustrates these lifecycle phases from a product development perspective. In the case of machine tools, it can be asserted that there are important opportunities to influence environmental impacts at the early design, detailed design and use phases in the product lifecycle.

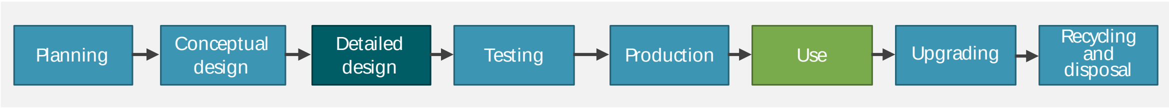

Figure 1: Product life cycle phases

Step 2 Assessment of product scope boundaries and associated impacts at the wider (extended product or product-system) level

The environmental impacts of machine tools are very sensitive to the product scope considered. Major shares of the energy consumption are determined not by the core machining process itself but by other components of the machine tool. The process periphery – including aspects like work-piece and tool handling, cleaning, heating, lighting and waste water conditioning - may also affect the environmental impacts of the overall product system (see Figure 2 for an overview illustration). Depending on the machine tool type, machine tools also often share loads with other products e.g. for compressed air use and cooling fluids and thus the energy flows considered need to take these into account.

Within a points-system approach, those impacts, which are determined by the product design, can be covered. ISO 14955 *Machine tools -- Environmental evaluation of machine tools -- Part 1: Design methodology for energy-efficient machine tools* (ISO 2014) also covers these aspects in the overall assessment scope.

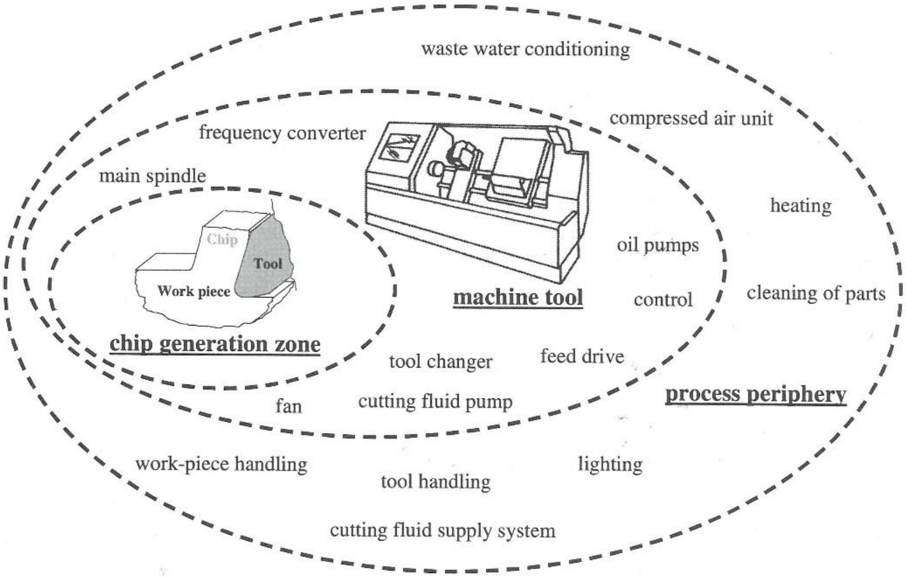

Figure 2: System boundary of the machining process [Abele et al. 2005]

Step 3 Selection of environmental impact criteria

The main environmental impact of a machine tool is the energy use in the use phase. Other impacts resulting from the use of chemicals (e.g. cutting fluids, lubricants) are usually regarded as being of comparatively minor importance. However, this has to be cross-checked via the results derived via the streamlined LCA "MEErP" (Kemna et al. 2011) process that is pursued in any "conventional" Preparatory Study related to Ecodesign product groups.

Material efficiency is another important impact factor. The reduction of scrap production, and reducing the proportion of rejected sub-quality finished end-product machined parts, will both lead to a lower energy use. The effect of reducing the embodied energy will also be taken into account, but as a further criterion in the checklist during the stage ("Stage 1") of product development, and hence on an ordinal scale rather than a cardinal scale, though not as part of the energy impact assessment ("Stage 2"). Figure 10, and the discussions in Section 8, give further details as to these proposals.

Given this, the majority of the case study focuses on the impact of energy in use, rather than a multi-criterion analysis encompassing different environmental impacts.

Step 4 Determination of the phases at which product design may influence lifecycle impacts

The earliest stages of product development have the highest impact on the final energy use. The selection of the working principle for the desired functionality as well as other general considerations impact the final energy use more than the decisions taken in the subsequent detailed design phase, where the components are selected and designed in detail, as shown illustratively in Figure 3.

Whilst on the one hand the earlier concept and design stages offer the greatest potential possibilities for design improvements, or product-service alternative ideas, on the other hand, the potential to concretely assess environmental impacts via measurement or simulation in those early stages is rather low.

However, at these earlier conceptual stages, modularity of design, the possibilities for modules to be upgraded in the future, and access to the machine's modules to facilitate reparability and ease of maintenance can be considered, and incorporated, as feasible and desirable.

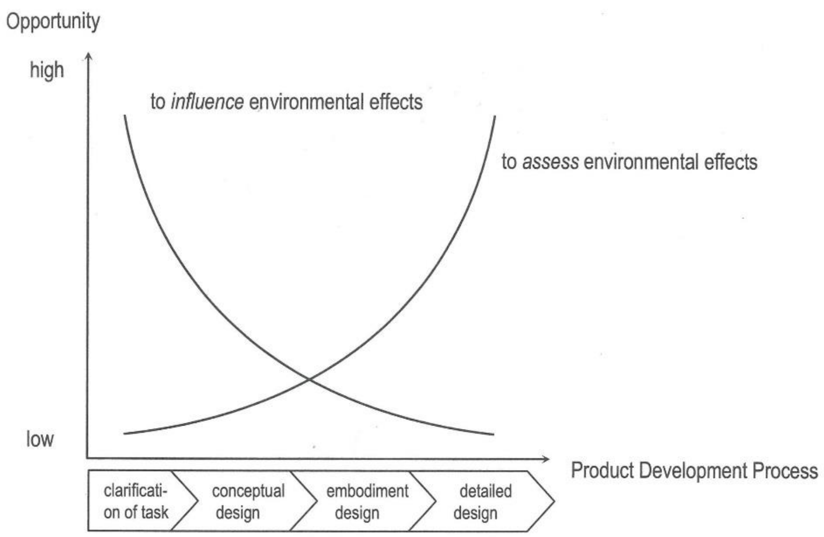

Figure 3: opportunities to influence and assess environmental impacts during the product development process [Atik 2001]

In the detailed design phase, the product designer has a very direct influence on the product’s environmental impacts, as (s)he is selecting and designing the individual components of the product. The potential to assess those impacts in detail via measurement, iterative analysis and potential iterative design changes is very high, i.e. it is more straightforward to assess these lower magnitude impacts than it is for the potential (but ambiguous) possibilities to achieve higher magnitude design change impacts in the early design phase.

Furthermore, the way the product is subsequently used has a very significant impact on its energy consumption and thus measures that influence user behaviour are important and need to be taken into consideration. Nonetheless the potential for the designer to influence user behaviour is limited and subject to high uncertainty.

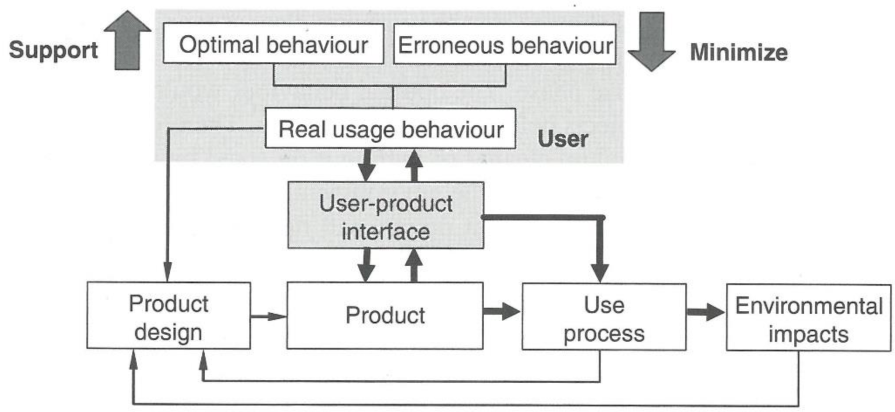

Figure 4: User-product interface [Abele 2005]

For the purpose of our analysis we distinguish three stages:

- product development (including testing, production and disposal)
- detailed product design
- the use phase.

Those stages are described in more detail in the following paragraphs.

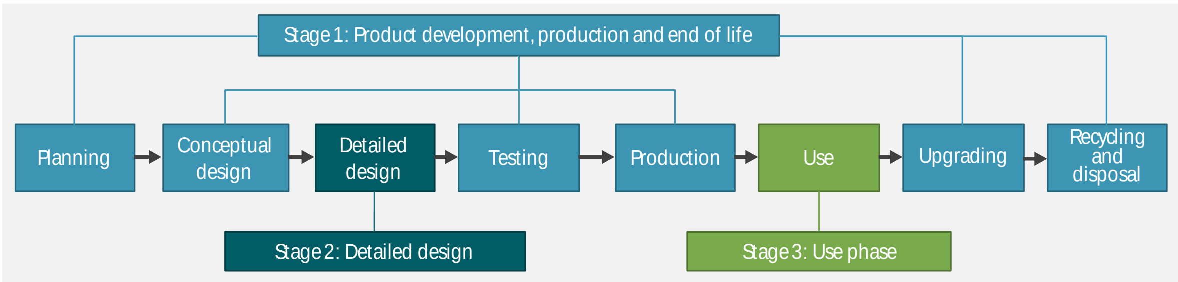

Figure 5: The three product stages (Stages 1, 2 and 3) that have most impact on machine tool energy consumption

The product development stage

Content of the stage:

This first stage is characterized by planning activities, conceptual thinking and the overall (environmental) management without going into the concrete design and specifications of the product. Furthermore, this stage also contains aspects of the subsequent phases after the stage of the detailed product design until the end-of-use, a potential upgrading and recycling of the product. The first stage contains those aspects which are not directly quantifiable, and which are more related to sustainable life-cycle-thinking. Criteria which might thereby play a role are quite heterogeneous, including, for example, considering issues such as the potential to: substitute energy-intensive materials; increasing material efficiency and reducing embodied energy, reduce friction; or "design for recycling", "design for upgrading", "design for light-weighting", etc. Taking different approaches for "design for x" into account assumes that the machine tool consists of different modules which might be replaced, repaired or recycled. Especially the upgrading of different machine modules offers the possibility to increase energy efficiency by adding more favourable modules or components at a later time. Since this effect is quite hard to determine ex ante and due to the high heterogeneity of components, such a future effects are not possible to include adequately in the present assessment. For that reason, there is no attempt to quantify this impact. Instead, it is proposed to reward this "design for x"-thinking in the early stages, in a qualitative manner.

Potential sources of good/ best practice for product and process design strategies:

A first set of criteria can therefore be derived from ISO 14955-1:2014 Annex A: "Overall machine concept", (ISO 2014) see *Figure* 6, or from Preparatory Study (ENTR Lot 5) (Schischke et al. 2012), from the Working Document for the Ecodesign Consultation Forum, May 2014 (EC 2014)[1] or via the "Blue Competence" publication by VDMA, Figure 7 (VDMA (Ed.) 2013)[2].

Additional criteria like the use of virtual machining or the use of integrated ecodesign environments in the product development process can easily be included in the list of criteria.

[1] It should be noted that the Preparatory Study and the Working Document derive the measures from ISO 14955.
[2] Comparing Figure 7 to Figure 6, note that the features listed in Figure 7 are more related to overall (environmental) management rather than to direct design measures.

No.	Feature for improvemcnt	Description
1	Overall machine concept	
1-1	Minimization of moved masses	
1-2	Reduction of friction	Reduction of friction means less mechanical wear and higher quality and also should lead to energy reduction; various types of bearing possible (rolling bearing, sliding bearing, hydrostatic bearing): ecological aspect has to be considered by the choice of bearings as well.
1-3	Optimization of the electrical design	Check if the machine tool has been designed according to customer design requirements and operational range has been specified close to optimal working point; avoid adding up spare capacities (avoid over sizing/over-engineering).
1-4	Design for Instant machining without warm-up	Provisions for automatic temperature compensation.
1-5	Work piece clamping and tool clamping	Use best efficient technology
1-6	Multi-spindle/multi-work pieces machining	
1-7	Complete machining all sides	
1-8	Combination of various technologies (turning + milling + laser + grinding, etc.)	Combination of technologies in one machine, one-time mounting and adjusting may result in higher quality and higher yield and also causing less energy consumption
1-9	Axis clamping	Usage of axis clamping instead of active motor brake
1-10	Redundant axis	High acceleration with short-stroke axis reducing acceleration for long-range, heavy axis.
1-11	Increase output	Without utilization (production) or low output, the efficiency will be degraded.
1-12	Provide customer interaction to reduce consumption of resources	Give the operator provisions to interact when he expects downtime
1-13	Tool change during running spindle (milling machine tools used in a way to change tools very frequently)	Provision to allow a tool change during running spindle to avoid deceleration and acceleration of spindle.

Figure 6: Criteria from ISO 14955

	criteria
1	The company has defined goals for its products and staff that incorporate sustainability-aware action.
2	The design guidelines incorporate sustainability criteria that extend over all life phases of the product concerned.
3	The product documentation describes aspects of resource-economical operation and the relevant precautions taken with the product.
4	A concept is in place for professionally fit-for purpose disposal following the end of the useful lifetime.
5	The company's service capabilities include professionally expert consultancy on energy- and resource-economy during daily use of the product.
6	The company declares its willingness to quantify its measures for efficiency upgrading in its products as exemplified by at least one case study. This case study (or studies) may also be used by the participant within the framework of the Blue Competence campaign.
7	The company operates a management system in which sustainability-driven goals are also specified and monitored in the same way as quality targets and criteria. The commitment to continuous improvement (CIP) is a constituent part of this management system and also covers sustainability-related goals.
8	The issue of "sustainability" has for the company and its products been assigned to a person in the top management.

Figure 7: Criteria from Blue Competence

The detailed product design stage

Content of the stage:

The detailed product design stage focuses on the components of a product and how these can be selected and combined in the most energy-efficient way. To do so, first all the components have to be listed and then assessed with regards to their energy saving potential. Furthermore, it is necessary, or at least highly desirable, to avoid cases where features which increase the energy efficiency correlate with other features or components in a negative way (i.e., avoiding any unnecessary "trade-offs", wherever possible). Thus, combinations which would lead to those effects need to be detected and avoided.

Potential sources:

Potential opportunities and design options to improve machine tool energy-efficiency are set out in Annex A and B of ISO 14955-1:2014. As a first step, the saving potential of a machine tool design feature may be derived from the findings of the ENTR Lot 5 Preparatory Study (Schischke et al. 2012).

Measure	Cost effects (investment) Increase in total machinery invest (tendency)	Total machinery savings potential (tendency)
Option 1		
10.3 Minimise non-productive time	0%	5%
Option 2		
2.8 400V inverter systems to substitute 200V systems	0%	1%
Option 3		
2.1 Regenerative feedback of Inverter system (servo motor/spindle)	0%	0,5%
Option 4		
8.1 Controlled peripheral devices like mist extraction, chip conveyer, etc	0,2%	1%
Option 5		
7.10 Single master switch-off	1%	1%

Figure 8: Example of energy savings potentials from the use of machine tool design options as reported in ENTR Preparatory Study (Note option 1 should be considered to be associated with stage 3 [see later in this report], addressing the use phase)

The use phase

Content of the stage:

The use phase follows on the product development and design process and therefore focuses on the energy-efficient operation of the product. This stage is of great importance because most of the measures previously discussed could be counteracted by deficiencies in how the product is used. Therefore, this third stage can be seen as accompanying the first stage, while explicitly concentrating on the use phase.

Potential sources:

Annex A & B of ISO 14955-1:2014 under point 9: "Guidance for energy-efficient use" contains a list of user guidance on the operation of machine tools that is an appropriate listing of relevant criteria, as shown in Figure 9.

9	Guidance for energy-efficient use	
9-1	Optimization of work piece processing by die tryout	Workpiece processing by tryout off-machine; avoidance of inefficient operating time; use also possible in conceptual phase of machine tool production.
9-2	Provisions to reduce scrap production	Die monitoring, in-process control, optimized use of raw material, minimize waste, zero-defect production.
9-3	Provide customer information to reduce consumption of resources	Training of operators leads to energy-sensitive handling of the machine tool.
9-3-1	Information to user on energy-efficient use of the machine e.g. on/off programming of auxiliary devices (users manual, instruction)	Give the operator information e. g. how to interact when he expects downtime.
9-3-2	Information to user on optimized movements of axis	Means for optimization of movements of multiple axis systems (feeders, robots) to follow energy-optimized moving curves
9-3-3	Information to user on usable exergy	Provide information about type of exergy carrier (e.g. water) and temperature of medium to choose optimal means for recovery.
9-4	Minimize non-productive time	Without utilization (production) or low output the efficiency will be degraded. Means of improving output may be automatic die change systems, condition monitoring to prevent component failures, good diagnostic for quick trouble shooting etc.
9-5	Optimize productivity by reducing cycle time per part	An improved productivity reduces the portion of required basic load per part.

Figure 9: Criteria from ISO 14955-1:2014 "Guidance for energy-efficient use"

Step 5 Assessment of whether a points system approach is potentially merited or not

Especially when considering the use phase and the early design stages, it is clear that there is a need to recognise a broad mix of qualitative criteria for good product design as well as the more quantitative criteria considered in the detailed design phase. The environmental impacts of the qualitative/ stages, as pointed out earlier in Steps 3 and 4, are difficult to estimate with any accuracy in a quantifiable (cardinal) manner. Still, they are of major importance for the productivity, functionality and final environmental impacts of the selected product design.

Furthermore, a rigorous performance assessment method cannot always be applied for machine tools, as the definition of the functional unit is often very challenging and the overall impact of specific technological requirements partly outweighs the saving potentials of individual measures.

Step 6 Assessment of the implications of product modularity

Machine tools are inherently modular. They consist of a variety of different components/modules, each with their individual function. Those components/modules can be assessed and optimized individually. The interaction of the modules has to be covered by the consideration of the early design stages in parallel with the process of optimising individual modules.

Thus, in this case study we propose to construct analytical modules that apply to each machine component when assessed in the detailed design phase, and to then combine these with additional analytical modules. These additional modules address the impact on in-use energy consumption of the design process followed in the early design stage, and – separately - the quality of user guidance provided. This is a hybrid approach that combines modularity in component function with modularity in the phases at which product design may influence lifecycle impacts, and it is thus fully in line with the thinking expressed in the Task 3 methodology. Importantly, it also blends cardinal and qualitative inputs, as per Step 5.

Step 7 Assessment of the implications of product performance sensitivity to the final application

A machine tool's environmental impact is highly sensitive to the use profile (duty profile) of the final application. In general it can be said that the share of the different operational states of the machine tool have an important impact on the final energy consumption, but are also sensitive to the final application.

While the energy demand during productive modes is rather independent of the actual application of the machine (but not of the overall design itself), the energy consumed in the times of productive operation can vary substantially depending on the actual product being made and on the mode of production. For example, the same machine tool can be used for batch or single unit production yet these are likely to have quite different energy requirements per machined work piece produced. The work piece characteristics also have an impact on energy use itself as well as the ratio between the operational and set-up/idle times, and these can vary from one job to another. Thus heterogeneity in the machine tool design, the pieces being machined and the mode of production render it difficult to define generic duty profiles for many classes of machine tools. Furthermore, while it may be possible to map some classes of machine tool to some types of application, such that representative duty profiles could be established in these cases, it is beyond the scope of the current study to investigate this issue and to establish under what circumstances acceptable generic duty profiles could be defined. Nonetheless it is clear that there will also be many cases where the machine tools and their applications are too heterogeneous for adequately representative duty profiles to be established across the classes of machine tool and applications concerned.

Nevertheless, the designer of a machine tool will aim to optimize the product for a selected number of typical use cases. In addition, the intended application of a machine tool will generally be indicated during the design phase and before placing the product on the market. Thus any given machine tool designer can either be expected to know enough about the intended use of the tool to be able to define suitable duty profiles during the design process, or to be able to make use of generic duty profiles when the machine tool is destined for more generic (and predictable) applications. In both cases duty profiles will be assumed and hence could be used for Ecodesign assessment providing the working assumptions are documented and made available.

Note, as the energy budget calculations of Step 8 make use of the duty profiles, in theory it is possible to apply the same approach to determine the sensitivity of the points outcomes to the duty profile. Thus the methodology could provide a means of establishing the validity, or otherwise, of any prospective generic duty profiles being considered for the more predictable machine tool class and application combinations.

Step 8 Determination of environmental impact budgets

As previously discussed in Step 4 the environmental impact budgets to be developed in this step (8) will need to take account of the product development stage, the detailed design stage and the use phase.

The Task 3 methodology requires each stage to be allocated a proportion of the total machine tool energy consumption in proportion to its impact on the overall energy consumption. For Stages 1 and 3 this is not measurable in any normal sense and hence a process would need to be agreed to decide what proportion of the total energy budget these would be allocated, noting that these Stages do not actually consume energy, but help to save it. Thus, these Stages would need to be awarded a part of the overall Step 8 energy budget that reflects their expected contribution to the whole machine tool's energy performance.

Each of these is now considered in turn as if they were distinct modules in the environmental impact budget. In line with the Task 3 methodology these stages are then aggregated at the end of this step prior to normalisation in Step 9. In this case study we only consider energy performance in a cardinal manner, and thus all the stages address this specific environmental impact parameter However, we propose that other criteria, for example the reduction of embodied energy, be considered in a ordinal manner.

8.1 The product development stage

Assessment:

The objective during the product development stage is to encourage machine tool designers to adopt a design process that considers the environmental impact of their designs and systematically considers the means to reduce them.

A checklist methodology to be followed during the design process is probably the most straightforward means of promoting this. Defining exactly which criteria should be part of the list is something that would need to be established in a more detailed analysis of all the potential checklist elements and their potential application. However, if such a process is to be usable within an Ecodesign regulatory context, then it would need to be structured in such a way that the quality of the process followed can be verified by a third party as needed. Self-declaration, third party audit and the provision of additional material (such as detailed documentation) could all have a role to play, in order to satisfactorily demonstrate that the relevant aspects were truly considered, and have been achieved. ***In principle, the degree of credible evidence put forward as proof that the checklist methodology was followed and applied could also be incorporated into the points assessment for this stage, such that stronger documentation or a voluntary third party audit could be given a higher weighting than would weaker documentation and self-declaration.***

An illustrative checklist for determining the score regarding the consideration of ecodesign thinking in the stage of product development is depicted in the following table in the case of a machine tool (for example for a multifunctional milling centre).

The first column serves to register if the listed aspect can be taken into consideration or can be implemented. If it is not possible to implement a certain aspect, this will be considered regarding the achievable score. Then, the second column demands whether it has been realised, and to what extent. The stated extent can be rated according to an ordinal scale:

Table 1: Realization of aspects and corresponding weightings

Realized to what extent	Explanation	Weighting of activity/-ies
not realized	no activities undertaken	0
Poorly realized	minor activities undertaken	1
Moderately realized	activities undertaken which offer a recognisable benefit	2
Well realized	activities undertaken which have a moderately high impact	3
Extremely well realised	Activities undertaken which have a high impact	4

The values assigned to the ordinal scale are used as weightings for the overall score achievable by these ordinal aspects. The decision and description should be briefly commented on in the third column and the action is verifiable via the additional information listed in column four. To pay attention to the different effort and evidence for the documentation, a weighting hierarchy is provided which is easy to understand and which does not compulsorily entail excessive documentation efforts for the manufacturers. Therefore, the following weighting is proposed. A simple self-declaration is rewarded with a weighting score of one. Providing evidence-based[3] documentation is taken into account by a weighting of two. Additionally, an external evaluation by a third party audit is weighting with a score of three. By choosing this weighting, the greater effort required for an external audit receives a higher weighting. However, the suggested score is not too excessive, such that manufacturers would be forced to have these audits performed for every aspect, in order to be able to attain sufficient points for the required minimum final score. Based on the documentation provided, it is possible to cross-check to what extent an aspect really was realised and evaluate the accuracy of the assigned score.

If all necessary information is provided and the aspect was realised to a high extent, a maximum of 12 points can be achieved (4 points for the degree of realization, multiplied by 3 points for the fullest and most reliable documentation, via a third party audit). If additional information to support verification is not given, or the short description is missing, no points at all are given. Where an aspect is impossible to implement, or to be considered, an explanation has to be given why. If the argument put forward is valid, this aspect is not considered when calculating the maximum achievable score. By following this logic, a generic checklist can be used which also takes the uniqueness of most machine tools into account. A worked example of a checklist is shown in Figure 10 and explained in the text below.

[3] “Evidence-based” means that the information can be revised by a reviewer, based on a physical or digital source. The evidence provided must be complete and auditable, and must allow the reviewer to obtain a full, in-depth insight as to how the aspect is realised.

General aspects for an eco-friendly product development:	**Possible?**	**To what extent realized (0-4)[1]**	**Short description**	**Verifiable by:**	**Weighting Factor[2]**	**Points achieved**
Sustainability criteria are taken into account during the whole product-life-cycle	✓	3	Checklist developed and used	Source [1]: Guideline	2	6
Main components that are susceptible to wear and tear have been well identified, and actions have been taken to prolong components' lifetime.	✓	0				
A concept for disposal of the product exists	✓	4	Guideline for disposal	Third party audit	3	12
Consultancy for considering energy-efficient aspects reagrding the intentended place of operation of the machine tool offered	✓	3	On-site consultancy	Self declaration	1	3
An upgrading of specific modules is feasible	✓	3	Modularity and interconnections taken into account. Components can be changed independently.	Source [2]: Blueprint	2	6
Machine tool specifc aspects for an eco-friendly product development:						
The complete machining all sides was considered			Not necessary, only working on one side			
The minimization of moved masses was considered	✓	4	Steel part substituted by an aluminium component. Further improvements not possible.	Source [3]: Blueprint	2	8
The reduction of friction was considered	✓	2	Partly: Would imply additional lubrication system. Low-friction bearings were implemented	Source [4]: Blueprint	2	4
Embodied energy was reduced	✓	2	By using a new processing method, the built-in materials were remarkably reduced. The use of the aluminium component increased embodied energy.	Third party audit	3	6
A multi spindle/multi work pieces machining was considered	✓	0			0	0
The combination of various technologies (turning + milling + laser + grinding, etc.) was considered	✓	1	Would increase complexity of the product.	Self declaration	1	1
Providing customer information to reduce consumption of resources was considered	✓	4	Personal instruction and information letter	Third party audit	3	12
					Max Points	Σ
					132	58

[1] 0 = not realized; 1 = poorly realized; 2 = moderately realized; 3 = well realized; 4 = extremely well realized

[2] 1 = Self declaration; 2 = internal documentation; 3 = third party verified documentation

Figure 10: Example machine tool checklist for the product development stage

In the above worked example, the first aspect regarding the consideration of sustainable criteria can be and was implemented based on a checklist (derived from the short description). However, it was implemented to its full extent, and hence this results in a score of three out of a possible 4. This is documented by a provided guideline explaining the checklist. This type of documentation is given a weighting of a factor of two. This leads to a score for this aspect of 3x2 = 6 (as shown in the column on the right). The next aspect could also be implemented or considered. However, it was not considered, and no further explanation was given as to why this was not done. Hence, this aspect receives a score of 0, and is also taken into account, when calculating the maximum number of points achievable. On the other hand, the aspect "Complete machining all sides" was also not implemented, but a reasonable and tenable explanation was given as to why. Because this explanation seems reasonable, this aspect is not considered when calculating the maximum score. Thus, in the case of these 12 potential aspects a maximum of 132 (i.e., 11 x 12) points can be achieved in this specific case (Number of aspects (12-1 =11 [since one was not relevant]) x Max. Points per aspect (12)).

8.2 The detailed product design stage

The assessment of the environmental impacts of the components will be carried out using a cardinal scale, assigning deemed energy savings for the different design options which can be applied to the module.

To assess the energy performance of a machine tool all the core modules (e.g. drive unit, pneumatic system, etc.) of the product must first be listed and for each module a correlation matrix with the potential design options is created.

The modules are named and identified in accordance with ISO 14955-1:2014:

- Overall machine concept
- Drive units
- Hydraulic systems
- Pneumatic systems
- Electric systems
- Cooling lubrication system/Die cooling/lubrication system
- Cooling system
- Peripheral devices
- *Guidance for energy efficient use*[4]
- Control systems

The assessment within this step is comprised of several sub-steps:

1. Definition and population of the design option measure correlation matrix
2. Identification of the relevant operating states
3. Identification of generic energy saving potentials
4. Identification of the case for assessment
5. Identification of the reference case
6. Identification of the BAT case
7. Determination of relative performance of the selected design

Definition of the correlation matrix

For each of these modules, ISO 14955-1:2014 defines potential energy saving options. The implementation of those saving options may be exclusive. Thus a correlation matrix for all potential saving options has to be created to determine which options ***are*** mutually exclusive.

[4] Not relevant for the detailed design phase, but considered for the use phase.

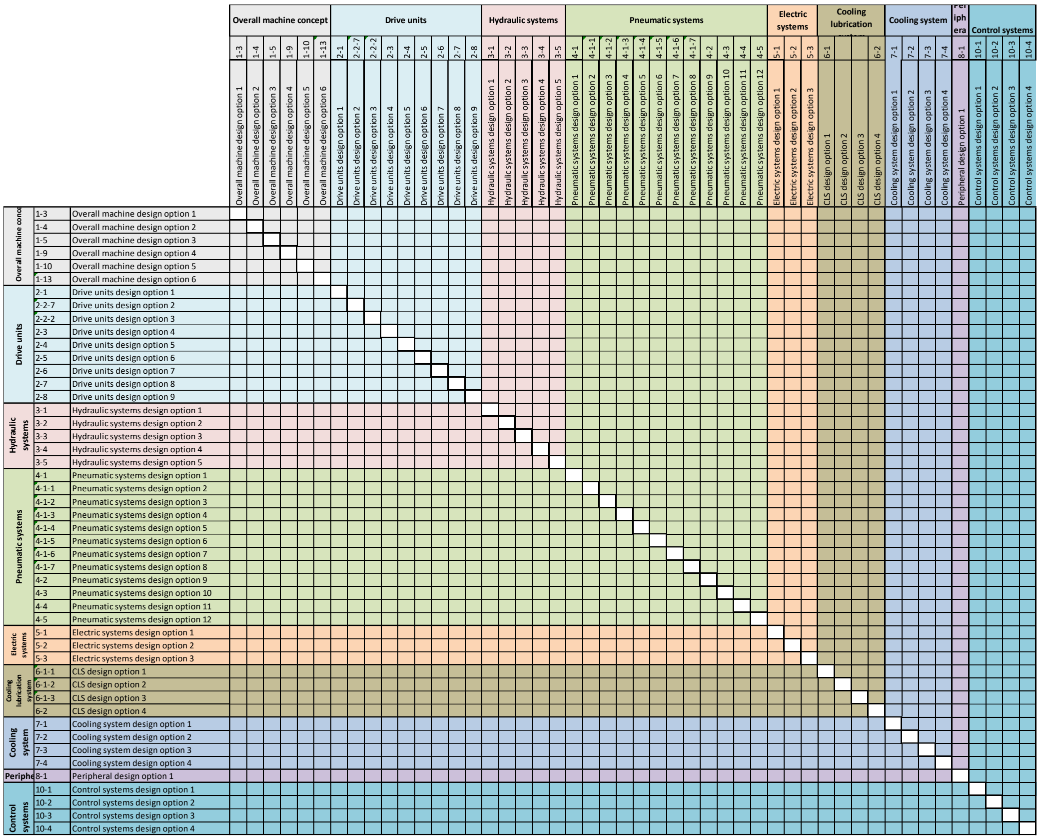

Figure 11: Empty example correlation matrix for a machine tool

Based on this correlation matrix a pairwise comparison of all features is conducted. The objective of this comparison is on the one hand the elimination of features which are not feasible or offer no benefit and on the other hand, to detect those features which are mutually exclusive. In the latter case, the option offering the higher saving potential should be considered.[5]

In the following figures and text, the descriptions focus on a single example module (drive units – see the coloured sections of the figure), however, the same process would need to be followed for other modules.

[5] This is under the assumption that no other features are excluded by the choice. Otherwise, the overall saving potential has to be determined considering all exclusions.

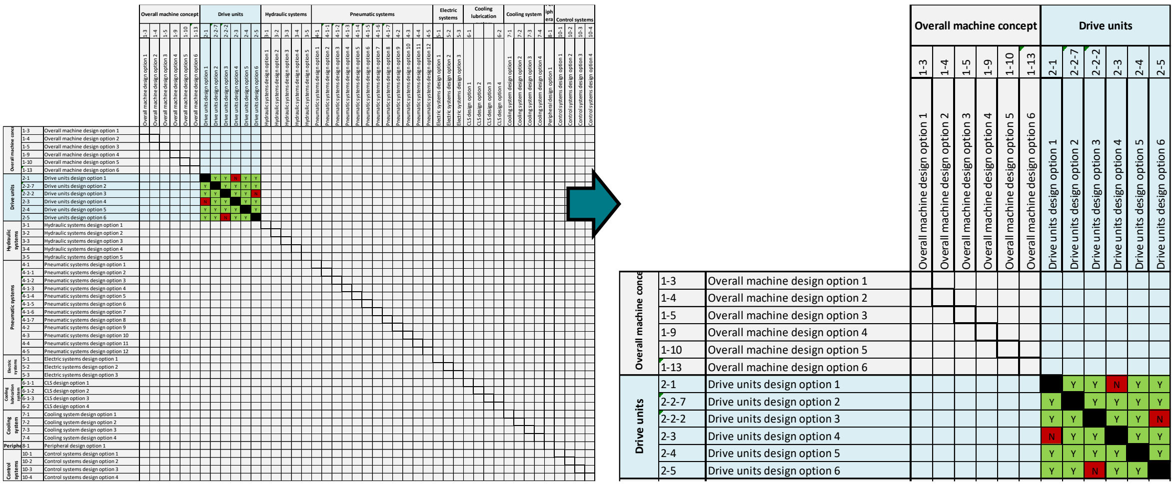

Figure 12: Population of the correlation matrix.

The compatibility of different combinations of energy efficiency design options is shown in the matrix below. For each combination of the different design option it is indicated, whether they can be combined in the product or not.

	Design option 1	Design option 2	Design option 3	Design option 4	Design option 5	Design option 6
Design option 1	n.a.	Possible	Possible	Not possible	Possible	Possible
Design option 2	Possible	n.a.	Possible	Possible	Possible	Possible
Design option 3	Possible	Possible	n.a.	Possible	Possible	Not possible
Design option 4	Not possible	Possible	Possible	n.a.	Possible	Possible
Design option 5	Possible	Possible	Possible	Possible	n.a.	Possible
Design option 6	Possible	Possible	Not possible	Possible	Possible	n.a.

Figure 13: Detailed view of the population matrix for one module

Identification of the relevant operating states

Next, for each module, the relevant operating states have to be identified. The operating states can be chosen in accordance with ISO 14955-1:2014, Annex D, but are not limited to this example. In the following tables, four operating states are used for illustrative purposes.

Identification of generic energy saving potentials

After defining the relevant operating states, generic energy savings have to be defined for each energy efficiency design option and for each operating state (preferably in accordance with ISO 14955). These energy savings should reflect a realistic saving potential, which can be achieved by the sound implementation of the respective energy saving measures. This results in a generic energy saving matrix for each module.

Table 2 shows an example for a hypothetical drive unit.

Those savings are defined for the individual savings. It is assumed that the combination of the design options can be calculated by a linear combination of the individual savings. Figure 13 shows which of these combinations can be realized in the product.

Table 2: Energy saving potentials for design options compared to the reference case

	Off	Standby with peripheral units off	Warm Up	Processing
Reference case	0.0	0.0	0.0	0.0
Design option 1	0.0	1 %	2 %	1 %
Design option 2	0.0	3 %	-2 %	2 %
Design option 3	0.0	1 %	2.5 %	2.5 %
Design option 4	0.0	2 %	3 %	1 %
Design option 5	0.0	3 %	2 %	3 %
Design option 6	0.0	1.5 %	1.75 %	4 %

Note that savings may be negative (as for design option 2 during the processing) if a saving option leads to increased energy use in one operating state.

Identification of the case for assessment

For the design option actually selected for the machine tool in question, the power intake and annual energy consumption have to be determined for each of the identified load states. Those values could either be determined by measurement or derived from the design calculations. Table 3 shows an example for a hypothetical drive unit.

The Fractions of time are derived from the operating hours of the product. The machine tool presented is off on most weekends leading to ~2200 Off mode hours. During workdays, the machine tool is operative for ~6.5 hrs. per day, in warm up for another ~3 hrs. and in standby for ~14.5 hrs.

Table 3: Energy use of the selected design (for a hypothetical drive unit)

	Off	Standby with peripheral units off	Warm-Up	Processing	Total
Fraction of time	25% (~2200 hrs.)	45% (~3950 hrs.)	10% (~850 hrs.)	20% (~1750 hrs)	100%
Power Intake (kW)	0.00	0.10	1.20	1.94	0.55
Energy use (MWh/year)	**0.0**	**0.8**	**10.5**	**17.0**	**4.8**

Identification of the reference case

For many Ecodesign assessments where an energy efficiency index is determined, the reference case is a product that is representative of the average energy performance on the market at a given time; however, whilst this is suitable for relatively uniform products, for which an energy efficiency index can be easily defined, it is much less suitable for highly heterogeneous products, whose performance is sensitive to the duty profile and task being set (i.e. nature of the workpiece and production run), such as machine tools. For machine tools, there are simply too many variables to have confidence in defining a generic energy efficiency index (as discussed in Step 7). ***Rather, it makes sense to use the approach set out in ISO 14955-1:2014 that lists energy savings design options and the typical savings expected from their use. Thus a reference case may be defined to be the product which has none of these energy saving features (as per***

Table 2***).*** This can be done on a module–by-module basis, which reflects the reality of machines tools being assemblies of modules for which there is more predictability, with regard to the impact of using different design options to influence their energy performance.

The purpose of having a reference case product is that it defines a benchmark against which the performance (energy efficiency in this case) of other products can be compared[6]. If the reference case is considered to be the product which has no energy saving design options, then it represents the solution with the least energy efficiency for the given task, and hence defines the lower performance boundary. By contrast, the best available technology (BAT) is the product which incorporates all the available and mutually compatible high efficiency design options, and hence defines the other end of the spectrum from the reference case. It should be noted that, since the energy efficiency design options are simply expressed in terms of energy savings potentials then no reference energy consumption level has been defined (rather, we define relative energy efficiencies depending on the design options used). Thus for performance declaration and verification purposes it would be necessary to see which design options have been deployed in a given design to determine its relative efficiency.

To determine the energy use of the reference system, the deemed energy savings or the energy demand in relation to the reference case have to be used to perform a backwards calculation of the reference case power intake.

Using the deemed savings from Table 3, the relative energy use of each design option can be calculated (remaining energy use = 1 - energy savings). The product of the remaining energy use of all selected design options for the selected design represents the overall savings of the selected design for each operating state. Table 4 shows an example of this type of calculation for a hypothetical machine tool drive unit module, in which two design options are incorporated into the actual design. As a result of both design options being implemented, the "actual design" comparative energy design compared to the reference case is calculated via the resulting percentage - for each column below – from multiplying the design option 1 percentage by the design option 2 percentage.

Table 4: Comparative energy demand: Selected design options compared to the reference case

	Off	Standby with peripheral units off	Warm-Up	Processing
Design option 1	100%	99%	98%	99%
Design option 2	100%	97%	102%	98%
Actual Design	100%	96%	100%	97%

Dividing the energy use of the selected design (which is determinable by measurement or design calculations) by the relative energy use values shown in Table 4 allows the energy use of the reference case to be calculated (as shown in Table 5). The values cited below are hypothetical, which would be derived from both the actual energy use of the selected design (which is known by measurement) and the (theoretical) deemed savings. This reference case has to be defined individually for each assessed product and load profile.

[6] A reference case is simply a product that can be used to define a benchmark performance level that is then used for comparison against other products having differing performance (energy efficiency in our case) levels.

Table 5: Energy use of the reference case hypothetical drive unit

	Off	Standby with peripheral units off	Warm-Up	Processing	Total
Fraction of time	25%	45%	10%	20%	100%
Power Intake (kW)	0.00	0.10	1.20	2.00	0.57
Energy use (MWh/year)	**0.0**	**0.9**	**10.5**	**17.5**	**4.9**

The absolute energy savings of the actual design are calculated as the difference in energy consumption to the reference case.

Identification of the BAT case

By knowing all feasible design options as well as their savings potentials, the total sum of savings for different design options can be determined for each module and load profile. The maximum savings achievable are determined once the following two parameters are known:

- The individual duty profile of the machine tool
- The potential combinations of design options.

A specific case has to be defined for each potential combination of design options. For each case, the overall savings (from the combination of energy savings design options) are then determined by considering the duty profile and savings potentials under each phase of the profile.

Two general cases have to be considered in building the BAT cases:

1. All design options decrease the energy demand for all stages of the duty profile
2. One or more design options increase(s) the energy demand in at least the "on" stage of the duty profile.

For both cases, the cases are built from the matrix of all potential combinations of measures, compared to the possible combinations (Figure 13, as previous). For example, a combination of design options 1,2,4 and 5 is not possible, as the options 1 and four are incompatible. The following Figure 14 shows the potential combinations with all exclusions marked in red. The combination of all design options and of five design options is not possible due to the exclusions. Therefore, the maximum of combinable design options is four. Four cases are possible using four design options.

All Design Options	1	2	3	4	5	6	not possible	
Five Design Options	1	2	3	4	5	n.a.	not possible	
	1	2	3	4	n.a.	6	not possible	
	1	2	3	n.a.	5	6	not possible	
	1	2	n.a.	4	5	6	not possible	
	1	n.a.	3	4	5	6	not possible	
	n.a.	2	3	4	5	6	not possible	
Four Design Options	1	2	3	4	n.a.	n.a.	not possible	
	1	2	3	n.a.	5	n.a.	possible	Case 1
	1	2	n.a.	4	5	n.a.	not possible	
	1	n.a.	3	4	5	n.a.	not possible	
	n.a.	2	3	4	5	n.a.	possible	Case 2
	1	2	3	n.a.	n.a.	6	not possible	
	1	2	n.a.	4	n.a.	6	not possible	
	1	n.a.	3	4	n.a.	6	not possible	
	n.a.	2	3	4	n.a.	6	not possible	
	1	2	n.a.	n.a.	5	6	possible	Case 3
	1	n.a.	3	n.a.	5	6	not possible	
	n.a.	2	3	n.a.	5	6	not possible	
	1	n.a.	n.a.	4	5	6	not possible	
	n.a.	2	n.a.	4	5	6	possible	Case 4
	n.a.	n.a.	3	4	5	6	not possible	

Figure 14: Combinations of four or more design options

In the first case (which is not applicable for the example), all the combinations that are a subset of another combination do not have to be considered, as they will lead to lower overall savings. If there were no negative savings, for example, case 5 in Table 6 (combination of the design options 1,3,5) will always have higher savings than all other combinations of the design options 1,3 and 5. Therefore, those other cases would not have to be considered.

In the second case, design options that give negative savings for certain stages of the load profile exist. A case without them must also be considered. In our example, one design option (design option 2) has negative savings in one operating state (i.e. duty profile stage). Thus, case 5 is derived from case 1 by removing design option 2.

The following Table 6 shows all combinations of three design measures. The design option with negative savings is marked in yellow. Only measures without this option are considered as cases, as all others are subsets of cases 1-4 with lower savings.

Three Design Options	1	2	3	n.a.	n.a.	n.a.	possible	subset of Case 1	
	1	2	n.a.	4	n.a.	n.a.	not possible		
	1	n.a.	3	4	n.a.	n.a.	not possible		
	n.a.	2	3	4	n.a.	n.a.	possible	subset of Case 2	
	1	2	n.a.	n.a.	5	n.a.	possible	subset of Case 1&3	
	1	n.a.	3	n.a.	5	n.a.	possible	subset of Case 1	Case 5
	n.a.	2	3	n.a.	5	n.a.	possible	subset of Case 1&2	
	1	n.a.	n.a.	4	5	n.a.	not possible		
	n.a.	2	n.a.	4	5	n.a.	possible	subset of Case 2&4	
	n.a.	n.a.	3	4	5	n.a.	possible	subset of Case 2	Case 7
	1	2	n.a.	n.a.	n.a.	6	possible	subset of Case 3	
	1	n.a.	3	n.a.	n.a.	6	not possible		
	n.a.	2	3	n.a.	n.a.	6	not possible		
	1	n.a.	n.a.	4	n.a.	6	not possible		
	n.a.	2	n.a.	4	n.a.	6	possible	subset of Case 4	
	n.a.	n.a.	3	4	n.a.	6	not possible		
	1	n.a.	n.a.	n.a.	5	6	possible	subset of Case 3	Case 6
	n.a.	2	n.a.	n.a.	5	6	possible	subset of Case 3&4	
	n.a.	n.a.	3	n.a.	5	6	not possible		
	n.a.	n.a.	n.a.	4	5	6	possible	subset of Case 4	Case 8

Figure 15: Combinations of three design options

Therefore, eight cases are relevant for the determination of the maximum savings in each operating state. The first four cases represent the potential combinations of the design options; cases 5-8 are their equivalents without design option 2.

Table 6: Considered combinations of the design options for the BAT case

Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8
Design option 1	Design option 1	Design option 2	Design option 2	Design option 1	Design option 1	Design option 3	Design option 4
Design option 2	Design option 2	Design option 3	Design option 4	Design option 3	Design option 5	Design option 4	Design option 5
Design option 3	Design option 5	Design option 4	Design option 5	Design option 5	Design option 6	Design option 5	Design option 6
Design option 5	Design option 6	Design option 5	Design option 6				

For each case (which might be the BAT case for our machine tool), the cumulative savings can be calculated by the multiplicative combination of the individual options (as already shown for the reference case in Table 5).

The reference case always has 100 % energy use. For example, case 5 includes design options 1, 3 and 5. They have savings of 1%, 1% and 3%.

The energy demand of case 5 in standby mode compared to the reference case is therefore calculated as the product of the three design options:

(100% - 1%)*(100% - 1%)*(100% - 3%) = 95 %

Table 7: Energy demand of the potential BAT cases compared to the reference case

	Off	Standby with peripheral units off	Warm Up	Processing
Case 1	100%	92%	96%	92%
Case 2	100%	92%	96%	90%
Case 3	100%	91%	95%	92%
Case 4	100%	92%	96%	89%
Case 5	100%	95%	94%	94%
Case 6	100%	95%	94%	92%
Case 7	100%	94%	93%	94%
Case 8	100%	95%	94%	91%

In our example, the maximum savings depend on the duty profile. In Standby mode, Case 3 has the highest savings, while Case 7 does in warm up and Case 4 does in full (processing) load. This means that the maximum savings can only be determined depending on the shares of operating states (duty profile stages) and the energy budget of the various operating states.

Therefore, the individual duty profile has to be included in the selection of the BAT case. Table 8 shows the potential energy use of the cases for the duty profile and energy use of the different load states. The fraction of time spent in each load profile mode is taken from Table 3.

Table 8: Potential energy use of the hypothetical drive unit cases

	Off	Standby with peripheral units off	Warm Up	Processing	Weighted Total
Fraction of time	25%	45%	10%	20%	100%
Energy use (MWh/year)					
Case 1	0.0	0.8	10.0	16.1	4.58
Case 2	0.0	0.8	10.1	15.8	4.54
Case 3	0.0	0.8	9.9	16.1	4.57
Case 4	0.0	0.8	10.1	15.6	4.49
Case 5	0.0	0.8	9.8	16.4	4.64
Case 6	0.0	0.8	9.9	16.2	4.60
Case 7	0.0	0.8	9.7	16.4	4.63
Case 8	0.0	0.8	9.9	15.9	4.54

In total, case 4 has the lowest total energy consumption and is selected as the BAT case.

From the above analyses it is now possible to define the energy use in each phase of the duty profile of the reference case, the BAT case and the selected design, as shown in Table 9 for the hypothetical drive unit. Therefore, the values for the reference case are derived from Table 5, values for the actual design from Table 3 and the values for the BAT from Table 8.

Table 9: Energy use of the reference case, selected design and BAT – example of a hypothetical drive unit

Energy use (MWh/year)	Off	Standby with peripheral units off	Warm Up	Processing	Weighted Total
Reference case	0.0	0.9	10.5	17.5	4.9
Actual design	0.0	0.8	10.5	17.0	4.8
BAT case	0.0	0.8	10.1	15.6	4.5

Treatment of additional machine tool modules

Exactly the same process can be repeated to determine the energy consumption of other modules. For example, if we consider that the same machine tool also has some peripheral devices then this could have a set of energy savings potentials by design option as shown in Table 10.

Table 10: Energy saving potentials for design options compared to the reference case for a hypothetical peripheral device module

	Off	Standby with peripheral units off	Warm Up	Processing
Reference case	0%	0%	0%	0%
Design option 1	0%	2.0%	3.0%	1.0%
Design option 2	0%	3.0%	2.0%	3.0%
Design option 3	0%	1.50%	1.75%	4.0%

For the design option which is actually selected for the machine tool in question, the power intake and annual energy consumption have to be determined for each of the identified load states. Those values could either be determined by measurement or derived from the design calculations. Table 11 shows an example for the hypothetical peripheral devices unit.

Table 11: Energy use of the selected design (for a hypothetical peripheral devices module)

	Off	Standby with peripheral units off	Warm Up	Processing	Total
Fraction of time	25%	10%	60%	5%	100%
Power Intake (kW)	0.00	0.05	3.62	7.51	1.89
Energy use (MWh/year)	**0.0**	**0.4**	**31.7**	**65.8**	**16.5**

Using the deemed savings from Table 10, the relative energy use of each design option can be calculated (remaining energy use = 1 - energy savings). The product of the remaining energy use of all selected design options for the selected design represents the overall savings of the selected design for each operating state. Table 4 shows an example of this type of calculation for a hypothetical machine tool drive unit module.

The relative energy demand of the actual design is calculated by a multiplication of the percentages of the individual design options (in this case "Design option 1" and

"Design option 2" are implemented in the product, Design option 3 is only relevant for the BAT case.).

Table 12: Energy demand of the selected design compared to the reference case for a hypothetical peripheral devices module

	Off	Standby with peripheral units off	Warm Up	Processing
Design option 1	100%	98%	97%	99%
Design option 2	100%	99%	98%	96%
Actual Design	100%	97%	95%	95%

By dividing the energy use of the selected design (which is determinable by measurement or design calculations) by the relative energy use values shown in Table 11, the energy use of the reference case is calculated, see Table 13. This value is a hypothetical value, derived from the actual energy use of the selected design (which is known by measurement) and the (theoretical) deemed savings. This case has to be defined individually for each assessed product and load profile.

Table 13: Energy use of the reference case hypothetical peripheral devices module (reference case)

	Off	Standby with peripheral units off	Warm Up	Processing	Total
Fraction of time	25%	10%	60%	5%	100%
Power Intake (kW)	0.00	0.05	3.80	7.90	1.98
Energy use (MWh/year)	**0.0**	**0.4**	**33.3**	**69.2**	**17.4**

The absolute energy savings of the actual design are calculated as the difference in energy consumption to the reference case.

The next step is to define the BAT case and this requires the compatibility of the design options to be assessed in the correlation matrix, Table 14. In this case there are less design options than for the hypothetical drive unit and all the design options are compatible so a single BAT case emerges which is the simple combination of all the design options i.e. of design options 1, 2 and 3.

Table 14: Design option correlation matrix for the hypothetical peripheral devices module

	Design option 1	Design option 2	Design option 3
Design option 1	n.a.	Possible	Possible
Design option 2	Possible	n.a.	Possible
Design option 3	Possible	Possible	n.a.

For this BAT case, the cumulative savings can be calculated by the multiplicative combination of the individual options (as already shown for the reference case in Table 13), see Table 15. The data is based on information from Table 10.

The energy demand of the BAT case (case 1) in standby mode compared to the reference case is therefore calculated as the product of the three design options:

(100% - 2%)*(100% - 3%)*(100% - 1,5%) = 94%

Table 15: Energy demand of the potential BAT case compared to the reference case

	Off	Standby with peripheral units off	Warm Up	Processing
Case 1	100%	94%	93%	92%

As there is only one case the duty profile and the power intake in the different operation states can simply be applied to determine the weighted energy consumption for the BAT case, Table 16. The duty profile is taken from Table 11.

Table 16: Potential energy use of the hypothetical peripheral devices module (BAT case)

	Off	Standby with peripheral units off	Warm Up	Processing	Total
Fraction of time	25%	10%	60%	5%	100%
Power Intake (kW)	0,00	0,05	3,55	7,28	1,83
Energy use (MWh/year)	0,00	0,41	31,09	63,80	16,1

From the above analyses it is now possible to define the energy use in each phase of the duty profile of the reference case, the BAT case and the selected design, as shown in Table 16 for the peripheral devices module. Therefore, the values for the reference case are derived from Table 13, values for the actual design from Table 11 and the values for the BAT from Table 16.

Table 17: Energy use of the reference case, selected design and BAT – example of a peripheral devices module

Energy use (MWh/year)	Off	Standby with peripheral units off	Warm Up	Processing	Weighted Total
Reference case	0.0	0.4	33.3	69.2	17.4
Actual design	0.0	0.4	31.7	65.8	16.5
BAT case	0.0	0.4	31.1	63.8	16.1

Combining modules to get the overall Stage 2 energy budget

At this stage the energy budgets of the machine tool are combined to derive an overall Stage 2 (detailed design stage) energy budget as shown in

Table 18. The data is based on the previous Table 9 (for the drive unit) and Table 17 (for the peripheral device).

Table 18: Combined energy budget for the detailed design stage (Stage 2) – hypothetical example of a machine tool with just two modules

Stage 2	Selected design energy budget (MWh/year)	Reference energy budget (MWh/year)	BAT energy budget (MWh/year)
Module 2.1 – drive unit	4.8	4.9	4.5
Module 2.2 – peripherals	16.5	17.4	16.1
Total	**21.3**	**22.3**	**20.5**

8.3 The use phase

As user behaviour has a significant impact on energy in use and in theory it is possible to improve machine tool operator actions by providing good guidance. This phase is intended to recognise the impact that such guidance can have on the product's final energy consumption.

The eco-design criteria in this stage are of a qualitative character and hence are very challenging to put on the same basis as the quantitative data considered in the previous stage (detailed design stage). However, they are of a very similar nature to those considered in the product development stage, and hence a checklist seems to be the most fitting method to assess these criteria.

This situation is a classic example of why a points system can be helpful because it can recognise degrees of progress towards an eco-design objective (in this instance reduced energy consumption) of both a quantifiable and qualitative nature and organise them within a common framework that allows some flexibility as to how the goal is achieved.

An example checklist for the case of a mechanical servo-press or mechanical presses, is shown below and is structured in the same manner as the one shown for the product development stage.

Accordingly, the means of completing the form and allocating the distribution of points also happens in the same way. The first column serves to register if the listed aspect can be realized at all, while the second column demands to what extent the aspect has been realized. The decision and description should be briefly commented on in the third column, and the action is verifiable via the additional information listed in column four. In the final column the points are awarded in accordance with the agreed structure. In this example, if all necessary information is provided and the aspect was realized to a high extent, a maximum of 12 points can be achieved (up to 4 points for the degree of realization, multiplied by up to 3 points for a fully documented case via a third party audit). If additional information to support verification is not given or the short description is missing, no points at all are given. In the case where an aspect is not possible to be implemented or considered, an explanation has to be given why. If the argument put forward is valid, this aspect is not considered when calculating the maximum achievable score. By following this logic, a generic checklist can be used, which also takes into account the uniqueness of most machine tools. An example of such a checklist with worked case study is shown below in Figure 16.

The aspect "provide customer information" is divided into three sub aspects. The points achieved for this criterion the average of the three sub-criteria.

General aspects for an eco-friendly product development:	Possible?	To what extent realized (0-4)[1]	Short description	Verifiable by:	Weighting Factor[2]		Points achieved (sub criteria)	Points achieved
Provisions to reduce scrap production	✓	4	Die monitoring as in-process control	Third party audit	3			12
Provide customer information to reduce consumption of resources (3 sub criteria)								
Information to user on energy-efficient use of the machine e.g. on/off programming of auxiliary devices (user manual, instruction)	✓	2	Not necessary, only working on one side	Source [1]: Manual	2		4	4
Information to user on optimized movements of axis	✓	0	Steel part substituted by an aluminium component. Further improvements not possible.				0	
Information to user on usable energy	✓	4	Partly: Would imply additional lubrication system. Low-friction bearings were implemented	Source [2]: Blueprint	2		8	
Minimize non-productive time	✓	4	By using a new processing method, the built-in materials were remarkably reduced. The use of the aluminium component increased embodied energy.	Self declaration	1			4
Optimize productivity by reducing cycle time per part	✓	3	Personal instruction and information letter					0
						Max Points		Σ
[1] 0 = not realized; 1 = poorly realized; 2 = moderately realized; 3 = well realized; 4 = extremely well realized [2] 1 = Self declaration; 2 = internal documentation; 3 = third party verified documentation						48		20

Figure 16: Example machine tool checklist for the user guidance phase

Defining exactly which criteria should be part of the list is something that would need to be established in a more detailed analysis. However, if such a process is to be usable within an Ecodesign regulatory context then it would need to be structured in such a way that the quality of the process followed can be verified by a third party as needed. Self-declaration, third party audit and the provision of additional material (such as detailed documentation), to demonstrate that the relevant aspects were truly considered, could all have a role to play. In principle, the degree of credible evidence put forward as proof that the checklist methodology was followed happens in the same way as already described in the case of the checklist for the product development stage. In addition, the weighting regarding the degree to which an aspect was realized occurs in the same manner.

The depicted example consists of 4 different aspects, while the aspect "Provide customer information to reduce consumption of resources" consists of three sub-aspects. In such a case, each aspect is assessed separately and the results of all aspects aggregated. In this case this would mean, that the sub-aspects achieve a score of 4,0 and 8 which leads to a sum of 12. For all the criteria a maximum of 36 points can be achieved. So the score for this aspect is: 12/36x12 = 4

Based on this example checklist a maximum score of 48 points can be achieved. The score attained is therefore 20 (12+4+4+0).

8.4 Step 8 summary

Under the Task 3 methodology, Step 8 entails establishing environmental impact budgets for each impact criterion and application group being considered. For this case study we have only considered energy consumption that occurs in the use-phase of the machine tool as this dominates the environmental impact of machine tools and is quite complex in its own right. As the energy consumption in use is known to be affected by the product development stage (i.e. the early design phase), the detailed design phase (where the technical design options for each machine tool module are decided), and the use phase (which is sensitive to user behaviour, which in turn can be affected by the quality of guidance provided on the optimal operation of the machine tool) then it is appropriate to structure the energy budget in a modular manner where there are three broad stages (one for the product development stage (qualitative), one for the detailed design stage (quantitative), and one for the user guidance offered (qualitative). To be consistent with the Task 3 methodology each of these broad stages needs to be allocated a share of the overall energy budget in proportion to their expected impact on the overall energy performance of the product.

Adjustment to Task 3 methodology

There is one significant adjustment to the Task 3 methodology and this concerns the treatment of the relationship between the duty profiles and the application groups. The task 3 methodology imagined that application groups would be defined based on the identification of whatever combination of product type and usage application would result in sufficiently stable representative duty profiles to enable an energy budget akin to an energy efficiency index to be defined. If no application groups with a stable duty profile could be defined, it proposed that the product was possibly therefore not suitable for a points-system approach for the environmental impact criterion being addressed.

In the case of machine tools there is so much heterogeneity that it may only be possible to identify a limited number of such application groups and these may not cover a large part of the machine tool market. However, the method put forward here based on ISO 14955-1:2014 avoids this problem because it defines the efficiency of individual modules via an assessment of the array of energy-saving design options they have used. Thus for any machine tool, even if it is completely customised and made to order, it is sufficient for the designer to specify and document the duty profiles that were envisaged during its conception (which will have been informed by the client's brief) and document the design options which were utilised, for the efficiency of each module to be determined. Then if the energy consumption of each module is measured or calculated when tested under the designated duty profile the energy budgets can be determined. This provides all the information required to follow the Task 3 methodology without needing the definition of application groups. To also avoid possible negative interactions between the specific modules right from the start, the development of a correlation matrix (as shown in Figure 11) on a module level might help to identify possible interferences. Whether this is really necessary depends on the complexity of the machine tool.

Assembling the energy budget

The final energy budget will thus comprise:

- a first stage to cover the product development stage (Stage 1)
- a set of stages that cover the detailed design stage (Stage 2)
- a last stage that covers the impact of user guidance (Stage 3)

The number of modules in the detailed design stage is a function of the number of modules used in the machine tool design and can address up to 8 areas within the ISO 14955-1:2014 methodology[7]. These can be designated as Module 2.1, Module 2.2, Module 2.3 etc. The Task 3 methodology requires each stage to be allocated a proportion of the total machine tool energy consumption in proportion to its impact on the overall energy consumption. For Stages 1 and 3 this is not measurable in any

[7] Drive units, hydraulic systems, pneumatic systems, electric systems, cooling lubrication system/die cooling/lubrication system, cooling system, peripheral devices, control systems

normal sense and hence a process would need to be agreed to decide what proportion of the total energy budget these would be allocated, noting that these Stages do not consume energy in actuality but help to save it. Thus, these Stages would need to be awarded a part of the overall Step 8 energy budget that reflects their expected contribution to the whole machine tool's energy performance. Where reliable performance data and information exist, it is possible to use this assembly of information to increase the reliability of these estimates. However, for some Stage 1 and Stage 3 features, it may be largely a matter of engineering judgement. As such, these would seem to be areas where a panel approach or, for example consulting experts via a pairwise Analytical Hierarchy Process (AHP) would be appropriate to help to reach a weighted decision. In this case study, we assume that Stages 1 and 3 are both assigned 20% each of the energy budget consumed by Stage 2, which addresses the detailed design stage and is the part of the energy budget that is directly measurable. This means that Stage 2 accounts for 71.4% of the total energy budget from all three stages added together i.e. from 100%/(20%+100%+20%) = 71.4%; however, a panel or expert decision-making group charged with making these determinations would be free to allocate whatever proportions to Stages 1 and 3 that they saw fit, based on the evidence at their disposal. Within Stage 2 the energy budgets allocated to each sub-module can either be measured directly (for each module), or, were it more practical, the whole machine energy use could be measured under the designated duty profile and design calculations used to allocate the proportions of the measured consumption associated with each sub-module.

Putting all this together to get an overall energy budget, as a precursor to the normalisation process of Step 9, results in the values reported in Table 19 for the specific hypothetical machine tool considered in this case study. Note, as previously discussed the Stage 1 and Stage 3 energy budgets are both simply 20% of the corresponding Stage 2 energy budget.

Table 19: Combined energy budget for all three stages (Stages 1, 2 and 3) – hypothetical example of a machine tool with just two modules

	Selected design energy budget (MWh/year)	Reference energy budget (MWh/year)	BAT energy budget (MWh/year)
Stage 1	**Product Development Stage**		
Module 1	**3.20 MWh**	**4.46 MWh**	**0.00 MWh**
Stage 2	**Detailed Design Stage**		
Module 2.1 – drive unit	4.83 MWh	4.95 MWh	4.49 MWh
Module 2.2 – peripherals	16.52 MWh	17.37 MWh	16.05 MWh
Sub-total	**21.35 MWh**	**22.32 MWh**	**20.54 MWh**
Stage 3	**Use Phase**		
Module 3	**3.42 MWh**	**4.46 MWh**	**0.00 MWh**
Total	**27.97 MWh**	**31.24 MWh**	**20.54 MWh**

Step 9 Normalisation and awarding of points

Issues of principle

The Task 3 methodology requires the values indicated in the energy budget to be normalised by comparison with a reference case product and this is then used to establish a performance indicator that can be converted into an overall point score.

In the specific application of the methodology set out above for machine tools the energy budget first has to be assessed for the detailed design stage (Stage 2) and then the allocations for the product development stage (Stage 1) and for the user guidance phase (Stage 3) are scaled from that. So if a machine tool was found to have an energy consumption of 10 MWh/year when tested under the designated duty profile, its Stage 2 consumption would be 10 MWh/year, while its Stage 1 and Stage 3 energy consumption would be 2 MWh/year each (assuming they account for 20% each of the total of all the stages). The chosen approach covers the principal components as well as the auxiliary components (e.g. cooling, ventilation, etc.) as they are covered by the modules in accordance with ISO 14955-1:2014. In this example, only a limited number of modules/components is considered. Module 2.2 represents peripheral units.

Note, what this implies is that optimising the product development process in line with the procedural checklist could save up to 2 MWh/year in the product's final energy consumption and that providing consumer guidance fully in line with the checklist could save a maximum of another 2 MWh/year. It is useful for a panel charged with setting the Stage 1 and 3 weightings to explicitly consider the proportion of savings they would expect to occur from these measures, as this helps to concentrate the thought process and encourages it to be more rigorous.

In addition, in this illustrative example, if Stage 1 and Stage 3 both counted for 20% of Stage 2 in the potential overall points allocations then Stage 2 would count for 71.4% of the potential total points (71.4% = 100/(20+100+20)). Stages 1 and 3 would then each account for 14.3% of the potential total points (14.3% = 20/(20+100+20)).

The points-allocation process defined in the Task 3 methodology is given on a scale of 0 to 100 and is related to the reference product which receives a score of 0. In this machine tool case study whatever the points allocations that are given for the checklist assessments for Stages 1 and 3 would be scaled to be out of a maximum of 100 and then multiplied by their stage's allocated weighting of the total points (14.3% each in this example). Similarly, the maximum potential points score for Stage 2 is also 100 but then multiplied by 71.4% to account for its share of the total points-allocation.

The detailed design stage, Stage 2, needs to be processed exactly as set out in the Task 3 methodology to establish the points to be allocated to that section.

Application in a worked example

The above outline is now applied to the worked example considered in this case study. In line with the Task 3 methodology, the first step is to normalise the energy budgets compared to the reference case by dividing them by the reference case, and then expressing the values as a percentage, as shown in Table 20. Those values are a normalization of the values in Table 19.

Table 20: Normalised combined energy budget for all three stages (Stages 1, 2 and 3) – hypothetical example of a machine tool with just two modules

	Normalised energy budget for the selected design	Normalised reference case energy budget	Normalised BAT energy budget
Stage 1	**Product Development Stage**		
Module 1	**71.7%**	**100.0%**	**0%**
Stage 2	**Detailed Design Stage**		
Module 2.1 – drive unit	97.6%	100.0%	90.6%
Module 2.2 – peripherals	95.1%	100.0%	92.4%
Sub-total	**95.7%**	**100.0%**	**92.0%**
Stage 3	**Use Phase**		
Module 3	**76.7%**	**100.0%**	**0%**
Total	**89.5%**	**100.0%**	**66.0%**

Note, the approach describes below only really uses this information for the Stage 2 points allocation calculation – the Stage 1 and 3 points calculations are done in a slightly simpler but equivalent manner as described below.

The points are then calculated as follows:

Stage 1 – Product development stage

If we imagine that the specific product in question scored a total of 46 out of a maximum potential score of 60 points for this stage in line with the approach discussed in section 8.1 then the points allocated for Stage 1 would be (46/60)*(100)*0.143 = 11.0.

Stage 2 – Detailed design stage

The selected design has a normalised Stage 2 energy budget of 95.7% (compared to the reference case of 100%) while the best available technology has a normalised energy budget of 92.0%. Under the Task 3 methodology the reference case product scores 0 points and the best attainable product scores 100. The choice is open to the designer of the points scheme as to whether they set the high-performance end-point of the points scale at the BAT energy budget level or at an energy budget of zero. In the present case study for machine tools it makes sense to use the BAT as the high-performance end-point of the points scale because the methodology does not enable higher savings to be allocated than the BAT (it is based on using a published list of energy savings potentials per design option and not on performance measurement). Thus if the BAT scores 100 points and the Reference Case scores zero points, the specific product in question will score = 100*(100-95.7)/(100-92) = 53.75. However, this is the score within Stage 2 itself and this needs to be multiplied by 0.714 (=100%/(20%+20%+100%)) to get the points score that is to be added to the other Stages i.e. 0.714*53.75 = 34.3 points for Stage 2.

Stage 3 – Use phase

If we imagine that the specific product in question scored a total of 43 out of a maximum potential score of 60 points for this stage in line with the approach discussed in section 8.1 then the points allocated for Stage 3 would be (43/60)*(100)*0.143 = 10.2.

Total points

Summing the three sets of points for Stages 1, 2 and 3 gives a final points-score (out of a possible 100) for the specific product considered in this case study of 55.5 (=11.0+34.3+10.2).

Other considerations and conclusions

This case study has been confined to addressing energy performance in the use phase because this is already a major challenge for machine tools and is the dominant environmental impact; however, it is certainly conceivable that other environmental impacts could be treated using a similar methodology.

As already mentioned in the beginning, the Task 3 methodology has been tested in this case study for the energy performance of machine tools and in principle it has been established that the method:

- seems to be suitable to assess energy performance
- enables complexity to be addressed
- recognises and rewards good eco-design practice
- is designed to award points for design options in proportion to their expected effect on the impact parameter in question
- is as comprehensive and inclusive as possible and allows the option to extend the scheme’s structure to include: the environmental impacts deemed appropriate (energy performance in this case), the product scope that is deemed most appropriate, the intervention phases deemed appropriate
- is capable not only of working at whatever application grouping levels are deemed to be appropriate but even for unique customised machine tool designs
- is adapted to address product modularity
- fits within the MEErP methodology, although it does not require some of the steps, and does require the input of detailed information on expected savings from using specific design options at the module level
- is capable of working with the Ecodesign and energy labelling regulatory process
- is technically feasible from a conformity assessment perspective but will require a more elaborate procedure than is the case for simpler products.

Nonetheless there are many areas that will still require further development and confirmation before this method could be deemed to be suitable to be applied to machine tools for Ecodesign regulatory purposes.

With regard to the savings potentials which are used the existing preparatory study has some information on design options and savings potentials, while the ISO 14955-1:2014 standard has more, but both are thought to be incomplete. Thus, additional work is needed to develop suitable lists of options and savings potentials, if these were to be applied in a points system for machine tools. In practice there are also likely to be some interactions between modules, which adds an additional layer of complexity to the derivation of such a list. As the method works on a module-by-module basis, any additional study charged with investigating these potentials in detail would need to not only conduct the assessment for each module of interest, but also examine the interactions between them. In the case study presented here it is assumed that there is full confidence in the savings potentials ascribed. However, if that is not the case, then the Task 3 methodology includes a possible approach for discounting less certain energy savings, which could be applied to address this issue. This approach could also be used to discount uncertain savings due to interactions between modules.

With regard to the checklists to be used for the product development stage (Stage 1) and the in-use phase (Stage 3), work would be needed to verify which elements should be included in these lists (building on the ISO 14955-1:2014 work) and to determine the relative magnitude of the points that should be allocated to each element. The points allocation would also need to address the calibre of the supporting evidence that could be provided, to demonstrate that the criterion under scrutiny was really met, and to determine how to weight the points allocations accordingly. This is not an action within a MEErP study, but could be added in as a component of a later possible study, the sim of which would be to specifically investigate the design option savings potentials at the module level. Inputs to such a step could potentially comprise experts from standardisation Technical Committees (TCs), academics etc. An early integration into the process would ensure an intensive discussion with the stakeholders.

The consultants could assemble the information to inform this and present it to the stakeholders and Consultation Forum, prior to the Commission drafting a proposal that would be scrutinised by the Consultation Forum and Regulatory Committee. Although from a "streamlined" regulatory mandate perspective, it might seem ideal, if the Regulatory Committee formed the Panel to decide (by voting if necessary) on the criteria and points allocations to be used within these two stages, in practice this might not function well, or be sufficiently independent or transparent. Such a process as decided by the Regulatory Committee either come too late in the process to be viable, or would require the Regulatory Committee to meet more than once, with its mandate consisting of different tasks. Given these constraints, it is likely the Commission would need to find another means of establishing a panel and then ask the Regulatory Committee to scrutinise and approve/disapprove of the findings of this panel, in much the same way as they currently undertake for draft regulations.

The Ecodesign regulatory process would also need to consider the weightings to be applied to Stages 1 and 3. In practice this would probably require some supporting technical investigation and preparation of a draft proposal for consideration by the Consultation Forum and subsequently the Regulatory Committee, who would ultimately be responsible for the decision made on this topic.

Conformity Assessment

From a conformity assessment perspective the methodology set out in this case study would require the machine tool supplier to provide evidence on the following:

- The check lists followed in Stages 1 and 3 with supporting evidence
- The duty profile(s) the machine tool is designed to satisfy
- The energy consumption of the machine tool when tested under that or those duty profile(s)

- The list of energy savings from the relevant design options, completed to show which options were excluded and why, and which options were selected for each module, with their predicted (and/ or measured) effects.

An MSA would then need to enter this information into the appropriate algorithms (ideally using a software tool) to check the points calculation. This is evidently a more complex process than is followed to verify compliance for less complex product types but is technically feasible.

It is also clear that applying such a methodology could be relatively time-consuming from the machine tool designer perspective if done for a complex machine tool comprising many modules. Explaining the algorithms used is certainly possible but would be susceptible to human error. Hence, it might be preferable if software were developed, to support the machine tool design process where the required informational inputs and algorithms were embedded in the program. The input files could be automatically updated each time there was a revision to the savings potentials options permitted by the method. Sharing the files could also facilitate any verification process.

Lastly, the methodology developed shows that a points-systems approach could be beneficial because it allows qualitative and quantitative eco-design benefits to be incorporated into the same accounting framework and this both rewards good eco-design practice and gives flexibility to the machine tool designer/supplier to decide how to meet any given points level; however, much of the methodological approach set out could also be used in a conventional Ecodesign regulatory approach where specific and generic requirements are specified. In principle, the specific requirements could be set around the Stage 2 (detailed design stage) performance levels using the methodology put forward to relate any actual machine’s performance to the equivalent reference case and BAT for the same machine. Whereas generic Ecodesign requirements could be set for Stage 1 (product development stage) and Stage 3 (use phase). Apart from the added flexibility the advantage of the points approach is that it can also be tuned to address uncertainty which is harder to do within a conventional Ecodesign approach. As there is still a great deal of uncertainty surrounding many of the elements applicable to machine tools, a softer and more flexible approach to promoting good eco-design practice perhaps has some merits, in this important facilitating industry sector for achieving further enhanced design product and process solutions.

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