PRESENTATION OF DRAFT TASK 4 REPORT - CASE STUDY OF GENERIC POINTS METHODOLOGY APPLIED TO MACHINE TOOLS

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INTRODUCTION & PREMISES

- Aim: Develop and demonstrate a theoretical approach which is able to address all kinds of machine tools
  - 1: Develop a points system approach
  - 2: Demonstrate it's principle suitability
- Machine tools are very heterogeneous, therefore 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.
- 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.

PREMISES TO CONSIDER THE SPECIAL CHARACTER OF MT

- The methodology is set out in the same steps (1-9) that are described in the Task 3 report
- But it is applied to the specific use case of machine tools by normalizing the performance score against the expected energy savings from the deployment of higher efficiency design option, compared to a base case, that does not have these design features.

- Thus this procedure is much fairer and even more flexible than as if attempts were made to define absolute base cases and duty cycles

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STEP 1: ASSESSMENT OF KEY LIFECYCLE STAGES

» 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.

» In the case of machine tools, it can be asserted that there are important opportunities to influence environmental impacts at the early design phase, detailed design phase and use phases in the product lifecycle

Planning → Conceptual design → Detailed design → Testing → Production → Use → Upgrading → Recycling and disposal

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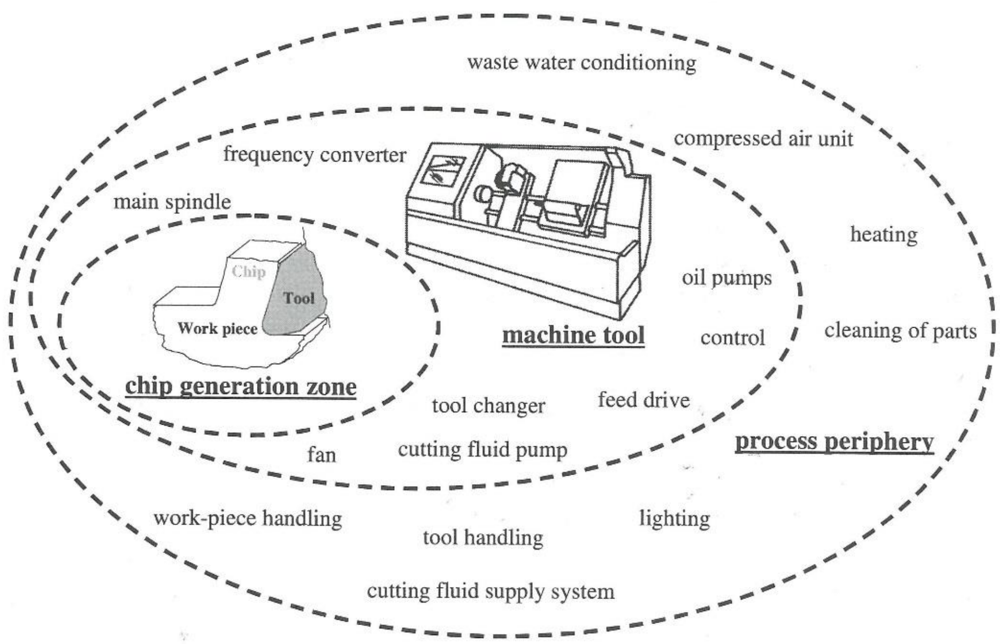
STEP 2: ASSESSMENT OF PRODUCT SCOPE BOUNDARIES AND ASSOCIATED IMPACTS AT THE WIDER LEVEL

- 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 and the process periphery
- 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

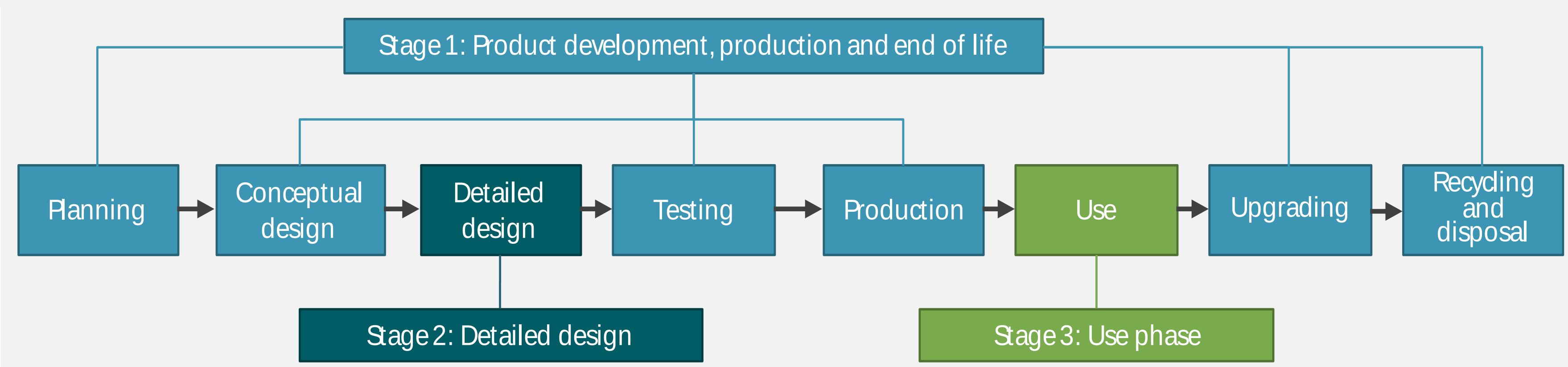


STEP 3: SELECTION OF ENVIRONMENTAL IMPACT CRITERIA

- 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.
- 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 and 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").
- Given this, the majority of the case study focuses on the impact of energy in use, rather than a multi-criteria 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 a high impact on the final energy use. But the potential to concretely assess environmental impacts via measurement, calculation or simulation in those early stages is rather low.
- 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 via measurement, iterative analysis and potential iterative design changes is very high.
- The way the product is finally used also has a very significant impact on its energy consumption and thus measures that influence the 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.



STEP 4-1: THE PRODUCT DEVELOPMENT STAGE

- This first stage is characterized by planning activities and conceptual thinking without going into the concrete design and specifications of the product
- The 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 substitute energy-intensive materials; increasing material efficiency, reducing embodied energy, etc.

Potential sources of good/ best practice for product and process design strategies an a first set of criteria can therefore be derived from:

- ISO 14955-1:2014 Annex A: “Overall machine concept”, (ISO 2014),
- Preparatory Study (ENTR Lot 5) (Schischke et al. 2012),
- Working Document for the Ecodesign Consultation Forum, May 2014 (EC 2014)
- or via the “Blue Competence” publication (VDMA (Ed.) 2013)

STEP 4-2: THE DETAILED PRODUCT DESIGN 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.

» Thereby it is highly desirable, to avoid cases where features which increase the energy efficiency correlate with other features or components in a negative way.

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%

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STEP 4-3: THE USE PHASE

- The use phase 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 phase of use

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.

Potential sources:

- Annex A & B of ISO 14955-1:2014, point 9: "Guidance for energy-efficient use" contains a list of user guidance on the operation of machine tools and can be used as a starting point.

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 manner. Still, they are of major importance for the productivity, functionality and final environmental impacts of the selected product design.
- A rigorous performance assessment method cannot always be applied for machine tools, as the definition of the functional units 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 its 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 proposed 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.
- Thus, 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.

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 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.
- » Thus heterogeneity in the machine tool design, the pieces being machined and the mode of production render it <u>difficult to define generic duty profiles</u> for many classes of machine tools.
- » Nonetheless it is clear that there will also be many cases where the machine tools and their applications <u>are too heterogeneous for adequately representative duty profiles.</u>

STEP 7: ASSESSMENT OF THE IMPLICATIONS OF PRODUCT PERFORMANCE SENSITIVITY TO THE FINAL APPLICATION

But:

» 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 <u>define suitable duty profiles</u> during the design process,

  » or to be able to <u>make use of generic duty profiles</u> when the machine tool is considered for more generic (and predictable) applications

» In both cases duty profiles will be assumed and hence could be used for Ecodesign assessment.

STEP 8: DETERMINATION OF ENVIRONMENTAL IMPACT BUDGETS- PRELIMINARY REMARKS

- As previously discussed in Step 4 the environmental impact budgets to be developed in step 8 will need to take account of the product development stage, the detailed design stage and the use phase.
- 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, can also be considered, but in an ordinal way.

STEP 8-1: DETERMINATION OF ENVIRONMENTAL IMPACT BUDGETS- PRODUCT DEVELOPMENT STAGE

- 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.
- 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 could be given a higher weighting.

STEP 8-1: DETERMINATION OF ENVIRONMENTAL IMPACT BUDGETS- PRODUCT DEVELOPMENT STAGE

General aspects for an eco-friendly product development:	Possible?
Sustainability criteria are taken into account during the whole product-life-cycle	✓
Main components that are susceptible to wear and tear have been well identified, and actions have been taken to prolong components' lifetime.	✓
A concept for disposal of the product exists	✓
Consultancy for considering energy-efficient aspects reagrding the intentended place of operation of the machine tool offered	✓
An upgrading of specific modules is feasible	✓
Machine tool specifc aspects for an eco-friendly product development:	
The complete machining all sides was considered	
The minimization of moved masses was considered	✓
The reduction of friction was considered	✓
Embodied energy was reduced	✓
A multi spindle/multi work pieces machining was considered	✓
The combination of various technologies (turning + milling + laser + grinding, etc.) was considered	✓
Providing customer information to reduce consumption of resources was considered	✓

[1] 0 = not realized; 1 = poorly realized; 2 = moderately realized;

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

- » 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 maximum achievable score.

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STEP 8-1: DETERMINATION OF ENVIRONMENTAL IMPACT BUDGETS- PRODUCT DEVELOPMENT STAGE

General aspects for an eco-friendly product development:	Possible?	To what extent realized (0-4)[1]	Short description
Sustainability criteria are taken into account during the whole product-life-cycle	✓	3	Checklist developed and used
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
Consultancy for considering energy-efficient aspects reagrding the intentended place of operation of the machine tool offered	✓	3	On-site consultancy
An upgrading of specific modules is feasible	✓	3	Modularity and interconnections taken into account. Components can be changed independently

» The second column demands whether it has been realised, and to what extent

» The values assigned to the ordinal scale are used as weightings for the overall score achievable by these ordinal aspects.

Realized to what extent	Explanation	Weighting of activity
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 realized	Activities undertaken which have a high impact	4

» The decision and description should be briefly commented on in the third column.

STEP 8-1: DETERMINATION OF ENVIRONMENTAL IMPACT BUDGETS- PRODUCT DEVELOPMENT STAGE

General aspects for an eco-friendly product development:	Possible?	To what extent realized (0-4)[1]	Short description	Verifiable by:	Weighting Factor[2]
Sustainability criteria are taken into account during the whole product-life-cycle	✓	3	Checklist developed and used	Source [1]: Guideline	2
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
Consultancy for considering energy-efficient aspects reagrding the intentended place of operation of the machine tool offered	✓	3	On-site consultancy	Self declaration	1
An upgrading of specific modules is feasible	✓	3	Modularity and interconnections taken into account. Components can be changed independently.	Source [2]: Blueprint	2
Machine tool specifc aspects for an eco-friendly					

- In column four, the action should be verifiable via the additional information
- To pay attention to the different degree of evidence for the documentation, a weighting hierarchy is provided:
  - A self-declaration is rewarded with a weighting score of one.
  - Providing evidence-based documentation is taken into account by a weighting of two.
  - An external evaluation by a third party audit is weighting with a score of three.

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STEP 8-1: DETERMINATION OF ENVIRONMENTAL IMPACT BUDGETS- PRODUCT DEVELOPMENT STAGE

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

- » 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 are given at all.
- » Where an aspect is impossible to be implemented, 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.

STEP 8-1: DETERMINATION OF ENVIRONMENTAL IMPACT BUDGETS- PRODUCT DEVELOPMENT STAGE

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

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STEP 8-2: DETERMINATION OF ENVIRONMENTAL IMPACT BUDGETS- DETAILED PRODUCT DESIGN STAGE

The assessment of the environmental impacts of the components will be carried out using a cardinal scale and by assigning deemed energy savings for the different design options which can be applied to a module (the modules are named and identified in accordance with ISO 14955-1:2014).

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

1. Definition and population of the design option in a 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

STEP 8-2: DETAILED PRODUCT DESIGN STAGE- DEFINITION OF THE CORRELATION MATRIX (1)

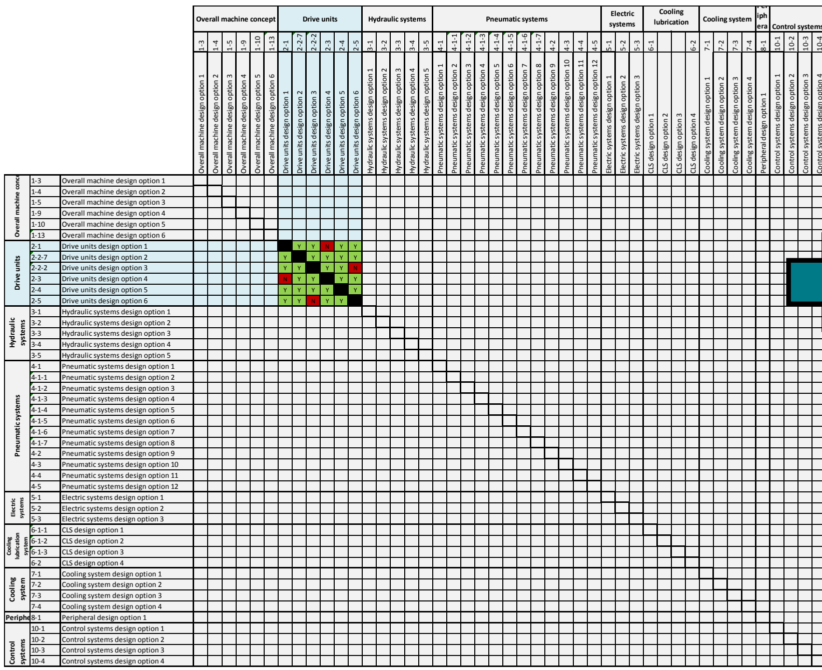
- For each of these modules, ISO 14955-1:2014 gives examples for potential energy saving options.
- The implementation of those saving options may be exclusive. Thus a correlation matrix for all potential saving options has to be created to determine which options are mutually exclusive.

Group	ID	Design option
Overall machine concept	1-3	Overall machine design option 1
	1-4	Overall machine design option 2
	1-5	Overall machine design option 3
	1-9	Overall machine design option 4
	1-10	Overall machine design option 5
	1-13	Overall machine design option 6
Drive units	2-1	Drive units design option 1
	2-2-7	Drive units design option 2
	2-2-2	Drive units design option 3
	2-3	Drive units design option 4
	2-4	Drive units design option 5
	2-5	Drive units design option 6
	2-6	Drive units design option 7
	2-7	Drive units design option 8
	2-8	Drive units design option 9
Hydraulic systems	3-1	Hydraulic systems design option 1
	3-2	Hydraulic systems design option 2
	3-3	Hydraulic systems design option 3
	3-4	Hydraulic systems design option 4
	3-5	Hydraulic systems design option 5
Pneumatic systems	4-1	Pneumatic systems design option 1
	4-1-1	Pneumatic systems design option 2
	4-1-2	Pneumatic systems design option 3
	4-1-3	Pneumatic systems design option 4
	4-1-4	Pneumatic systems design option 5
	4-1-5	Pneumatic systems design option 6
	4-1-6	Pneumatic systems design option 7
	4-1-7	Pneumatic systems design option 8
	4-2	Pneumatic systems design option 9
	4-3	Pneumatic systems design option 10
	4-4	Pneumatic systems design option 11
	4-5	Pneumatic systems design option 12
Electric systems	5-1	Electric systems design option 1
	5-2	Electric systems design option 2
	5-3	Electric systems design option 3
Cooling lubrication system	6-1-1	CLS design option 1
	6-1-2	CLS design option 2
	6-1-3	CLS design option 3
	6-2	CLS design option 4
Cooling system	7-1	Cooling system design option 1
	7-2	Cooling system design option 2
	7-3	Cooling system design option 3
	7-4	Cooling system design option 4
Periphe	8-1	Peripheral design option 1
Control systems	10-1	Control systems design option 1
	10-2	Control systems design option 2
	10-3	Control systems design option 3
	10-4	Control systems design option 4

- Based on this correlation matrix a pairwise comparison of all design options is conducted.
- The objective of this comparison is the elimination of options which are not feasible or offer no benefit
- And to detect those features which are mutually exclusive. In the latter case, the option offering the higher saving potential should be considered.

STEP 8-2: DETAILED PRODUCT DESIGN STAGE- DEFINITION OF THE CORRELATION MATRIX- EXAMPLE MODULE DRIVE UNIT (1)

The compatibility of different combinations of 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.



			Overall machine concept						Drive units					
			1-3	1-4	1-5	1-9	1-10	1-13	2-1	2-2-7	2-2-2	2-3	2-4	2-5
			Overall machine design option 1	Overall machine design option 2	Overall machine design option 3	Overall machine design option 4	Overall machine design option 5	Overall machine design option 6	Drive units design option 1	Drive units design option 2	Drive units design option 3	Drive units design option 4	Drive units design option 5	Drive units design option 6
Overall machine conce	1-3	Overall machine design option 1												
	1-4	Overall machine design option 2												
	1-5	Overall machine design option 3												
	1-9	Overall machine design option 4												
	1-10	Overall machine design option 5												
	1-13	Overall machine design option 6												
Drive units	2-1	Drive units design option 1								Y	Y	N	Y	Y
	2-2-7	Drive units design option 2							Y		Y	Y	Y	Y
	2-2-2	Drive units design option 3							Y	Y		Y	Y	N
	2-3	Drive units design option 4							N	Y	Y		Y	Y
	2-4	Drive units design option 5							Y	Y	Y	Y		Y
	2-5	Drive units design option 6							Y	Y	N	Y	Y	

	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.

STEP 8-2: DETAILED PRODUCT DESIGN STAGE- IDENTIFICATION OF THE RELEVANT OPERATING STATES (2)

» 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.

Off	Standby with peripheral units off	Warm Up	Processing

STEP 8-2: DETAILED PRODUCT DESIGN STAGE- IDENTIFICATION OF GENERIC ENERGY SAVING POTENTIALS (3)

- 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.
- This results in a generic energy saving matrix for each module. The table shows an example for a hypothetical drive unit.

Operating state	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 %

- 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. The correlation matrix shows which of these combinations can be realized in the product.
- It also may be that a saving option leads to an increased energy use in one operating state

STEP 8-2: DETAILED PRODUCT DESIGN STAGE- IDENTIFICATION OF THE CASE FOR ASSESSMENT (4)

- For the design options actually selected for the machine tool in question, the power intake and annual energy consumption have to be determined for each of the identified operating states.
- Those values could either be determined by measurement or derived from the design calculations.

- 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.

Actual design Energy use	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**

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STEP 8-2: DETAILED PRODUCT DESIGN STAGE- IDENTIFICATION OF THE REFERENCE CASE (5)

» 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 this is much less suitable for highly heterogeneous products, whose performance is sensitive to the duty profile and the task being set.

» For machine tools, there are simply too many variables to have confidence in defining a generic energy efficiency index. Rather, it makes sense to use the approach set out in ISO 14955-1:2014 that lists energy saving design options

» A first tendency for the typical savings expected from their use can be derived from the ENTR Lot 5 Preparatory Study (Schischke et al. 2012) .

» Thus a reference case may be defined to be a product which has none of these energy saving options.

STEP 8-2: DETAILED PRODUCT DESIGN STAGE-IDENTIFICATION OF THE REFERENCE CASE (5)

- 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.

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STEP 8-2: DETAILED PRODUCT DESIGN STAGE- IDENTIFICATION OF THE REFERENCE CASE (5)

» The table below 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" compared to the reference case is calculated via the resulting percentage from multiplying the design option 1 percentage by the design option 2 percentage.

	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 %

Actual design Relative energy use	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%

Derived from generic energy saving potentials (3)

STEP 8-2: DETAILED PRODUCT DESIGN STAGE- IDENTIFICATION OF THE REFERENCE CASE (5)

» By dividing the energy use of the selected design (determinable by measurement or design calculations) by the relative energy use values allows the energy use of the reference case to be calculated.

Actual design Energy use	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**

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Actual Design Relative energy use	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%

Reference case Energy use	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

Derived from generic energy saving potentials (3) and Identification of the case for assessment (4)

STEP 8-2: DETAILED PRODUCT DESIGN STAGE- IDENTIFICATION OF THE BAT CASE (6)
DEFINITION OF SPECIFIC CASES

- A specific case has to be defined for each potential combination of design options. For each case, the overall savings are then determined by considering the duty profile and savings potentials under each phase
- 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. For example, a combination of design options 1,2,4 and 5 is not possible, as the options 1 and 4 are incompatible.

	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.

Derived from the correlation matrix (1)

STEP 8-2: DETAILED PRODUCT DESIGN STAGE- IDENTIFICATION OF THE BAT CASE (6)

DEFINITION OF SPECIFIC CASES

» The following Figure 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	

STEP 8-2: DETAILED PRODUCT DESIGN STAGE- IDENTIFICATION OF THE BAT CASE (6)

DEFINTION OF SPECIFIC CASES

» The following Table shows all combinations of three design options.

» 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

	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	
Three Design Options	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

» So 8 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.

STEP 8-2: DETAILED PRODUCT DESIGN STAGE- IDENTIFICATION OF THE BAT CASE (6)
ENERGY DEMAND OF THE POTENTIAL BAT CASES COMPARED TO THE REFERENCE CASE

- 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
- 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%.

Case 5	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 %

- 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 %

Cumul. savings	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%

- 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.

Derived from generic energy saving potentials (3)

STEP 8-2: DETAILED PRODUCT DESIGN STAGE- IDENTIFICATION OF THE BAT CASE (6)

POTENTIAL ENERGY USE OF THE CASES FOR THE DUTY PROFILES

Cumul. savings	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%

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Energy use of Reference Case	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**

Energy Use BAT	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.

Derived from Identification of the reference case (5)

STEP 8-2: DETAILED PRODUCT DESIGN STAGE- IDENTIFICATION OF THE BAT CASE (6)
ENERGY DEMAND OF THE POTENTIAL BAT CASES COMPARED TO THE REFERENCE CASE

Based on the 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 following table for the hypothetical drive unit.

Energy use for the reference case

	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**

Energy use for the actual design

	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**

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 (Case 4)	0.0	0.8	10.1	15.6	4.5

STEP 8-2: DETAILED PRODUCT DESIGN STAGE- COMBINING MODULES TO GET THE OVERALL STAGE 2 ENERGY BUDGET

Also further modules can be taken into account in the same way (e.g. an exemplary peripheral device)

At this stage the energy budgets of the machine tool are combined to derive an overall Stage 2 energy budget.

Energy use for the 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 (Case 4)	0.0	0.8	10.1	15.6	4.5

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Energy use for the peripheral device

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

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**

STEP 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 of detailed design.
- However, they are of a very similar nature to those considered in the product development stage, and hence a checklist seems to be a fitting method to assess these criteria.
- Accordingly, the means of completing the form and allocating the distribution of points also happens in the same way.

STEP 8-4: ASSEMBLING THE ENERGY BUDGET

- To be consistent with the Task 3 methodology each of the three 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.
- 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 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%;

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STEP 8-4: ASSEMBLING THE ENERGY BUDGET

An overall energy budget, as a precursor to the normalization process of Step 9, results in the values reported below for the specific hypothetical machine tool considered in this case study.

	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**

Dep. on score

20 %

Clac. Energy use

Dep. on score

20 %

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STEP 9: NORMALISATION AND AWARDING OF POINTS

- 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 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.

	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% (43/60)**	**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% (46/60)**	**100.0%**	**0%**
Total	**89.5%**	**100.0%**	**66.0%**

Hypoth. score

STEP 9: NORMALISATION AND AWARDING OF POINTS - *TOTAL POINTS*

Stage 1 - Product development stage

If a hypothetical product scored a total of 43 out of a maximum potential score of 60 points The points allocated for Stage 1 would then be:

(43/60)*(100)*0.143 = 10.2.

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 BAT 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 (in this case the BAT).

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 further 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 a hypothetical product in question scored a total of 46 out of a maximum potential score of 60 points for this stage then the points allocated for Stage 3 would be

(46/60)*(100)*0.143 = 11.

STEP 9: NORMALISATION AND AWARDING OF POINTS - *TOTAL POINTS*

Stage 1 - Product development stage
Points allocated for Stage 1 would be (43/60)*(100)*0.143 = **10.2.**

Stage 2 - Detailed design stage
The specific product score = 100*(100-95.7)/(100-92) = 53.75.
0.714*53.75 = **34.3** points for Stage 2.

Stage 3 - Use phase
Points allocated for Stage 3 would be (46/60)*(100)*0.143 = **11.**

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).

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MARKET SURVEILLANCE FOR MACHINE TOOLS- FRAMEWORK

- Machine tools are very heterogeneous
- Therefore compared to products, where the MSA test the actual product's energy performance, the approach for conformity assessment according to the presented methodology is different.

  The requirements set out are either:

  » procedural, as for the stages 1 (Product development) and 3 (Use phase)

  » or technical as for stage 2 (Detailed design stage)

➢ The conformity assessment therefore will be of an audit type.

MARKET SURVEILLANCE FOR MACHINE TOOLS- INFORMATION TO BE PROVIDED

- For a conformity assessment the machine tool supplier would have to provide evidence on the following information:
  - The checklists 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.
  - A documentation of the calculations, preferably in a pre-defined format

MARKET SURVEILLANCE FOR MACHINE TOOLS-PROCEDURE

- Stages 1 and 3 (Checklists):
  - The MSA would only check, whether the evidence provided is appropriate and correct.
  - For selected cases, the MSA could also check, whether the procedural requirements are actually implemented in the company.
  - Regarding selected issues in stage 3, such as the user information, the MSA can check, whether this information is actually provided.
- Stage 2 (Calculation):
  - the MSA would first have to check plausibility, completeness and accuracy of the information provided by the manufacturer.
  - And would then need to enter the 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.

SUMMARY

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 also aligned to the ISO standard's process
- 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

SUMMARY

- A viable method has been developed and demonstrated that provides a fair basis for the Ecodesign evaluation of the machine tools (with regards to their energy performance).
- It is technically feasible from a conformity assessment perspective, but will require a more elaborate procedure than it is the case for simpler products.
- Discrete case studies have to be provided to demonstrate suitability of the generic approach
- A database for weightings has to be established

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Thank you for your patience and concentration