Energy-Using Product Group Analysis - Lot 5

Machine tools and related machinery

Task 6 Report – Improvement potential

Sustainable Industrial Policy - Building on the Ecodesign Directive - Energy-using Product Group Analysis/2

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Executive Summary – Task 6

Based on the improvement options identified in the BAT analysis of task 5, this task report now calculates the effect of these design options being implemented consecutively, their monetary consequences in terms of Life Cycle Cost for the user, their environmental costs and benefits, and pinpoints solutions with the Least Life Cycle Costs. This analysis builds on the Base Cases of Task 4. Although the implementation of options now refers each to “one unit of machine tool”, this is not meant to reflect real-world machine tools, but it does already include a consideration of market penetration rates.

For each of the Base Cases a consecutive order of design options has been identified, from one single option for simple non-numerically controlled (non-NC) machine tools, up to 22 options for highly complex machine tools. This range of complexities confirms again the philosophy that a multitude of options for numerically controlled (NC) machine tools can (and should) be considered. The analysis shows that the combination of options leads to moderate Total Energy savings potentials at the point of Least Life Cycle Costs, which are in the range of 3%-5% for the most relevant Base Cases, amongst which is the highly-relevant Base Case on CNC machining centres, but also Base Cases from the wood working sector. For welding equipment a Total Energy savings potential of 11,5% at Least Life Cycle Costs has been calculated. The sensitivity analyses conducted (including variation of use patterns, shift models, lifetime and energy costs) largely confirm the trends identified in the baseline analysis.

In general, there is no single option with a large environmental improvement potential. Moderate savings as stated can be realised only with the implementation of several individual options, via what could be called “good machinery design”. As this analysis was meant to address certain archetypal machine tools on a very generic level, it should not be ignored that there might be much larger environmental and energy savings potentials for particular machine tools under certain conditions, e.g. for specific applications.

6 Task 6 – Improvement potential

The scope of Task 6 is to identify design options, their monetary consequences in terms of Life Cycle Cost for the user, their environmental costs and benefits, their economic impacts, and to pinpoint the solution with the Least Life Cycle Costs (LLCC) and the Best Available Technology (BAT). The assessment of monetary Life Cycle Costs is relevant to indicate whether design solutions might impact the total user's expenditure over the total product life.

6.1 Identification of Design Options

The identification of design options is closely related to the analysis in Task 5, where numerous options are listed and were assessed. These options, reflecting both technology trends and environmentally motivated measures, complemented by further evidence, is now matched with the Base Cases calculated in Task 4. It has to be acknowledged that the assessment of design options in Task 5 is almost exclusively based on input from European manufacturers of machine tools, even though a large share of machine tools are also imported to the EU-27. There are no data available regarding the technical and environmental performance and related savings potentials of these imported machine tools, as such.

A multitude of design options is identified and is subject to an assessment as follows, in each case:

- Does this design option affect those input values of the EcoReport in the base case analysis which are of outstanding environmental relevancy?
- Based on a first screening: are there any technological, social, or economic hurdles foreseeable which might definitely hinder the implementation of this design option?

The environmental improvements of these options will be assessed quantitatively by using the EuP EcoReport.

Furthermore, options are not examined further, when they fulfil any of the following criteria:

- Significant negative impact on the functionality of the product, from the perspective of the user,
- Health and safety are adversely affected,

- Significant impact on industry's competitiveness,
- They have the consequence of imposing proprietary technology on manufacturers.

The following design options identified in Task 5 are related to **non-energy in use aspects**, but could not be generalised, or were related only to a low or moderate savings potential. However, in individual cases these options might be relevant, but could not be addressed in the following quantified analysis of improvement options[1]:

- Machine bed made of polymer concrete or similar (but observe end-of-life implications)
- Material savings aspect of light-weight components
- Machinery features, which reduce material cut-offs / waste (e.g. skeleton-free punching)
- Design measures to minimise cooling lubricants mist generation and enhance extraction
- Cooling lubricants saving effect of dry machining, MQL processes (as long as productivity is not hampered)
- Monitoring and control, leakage detection of media supply systems (cooling lubricants, process gases etc.) and related measures to reduce consumption of these media.

6.1.1 Metal working machine tools

6.1.1.1 Base Case 1 - CNC machine tools

Based on the estimates regarding improvement potentials and related cost effects stated in the Task 5 report, a consecutive implementation of options has to be modelled. According to the methodology for preparatory studies, the implementation of options has to start with those environmental improvements which feature the highest decrease of life cycle costs, followed by those measures which further reduce environmental impacts, but at higher life cycle costs. Using this approach, an order of options

[1] Note that besides these design options the analysis below actually covers a couple of non-energy in use options, such as design measures to change the material used for light-stationary woodworking machine tools, and to reduce excessive welding gas consumption

has been established for CNC machining centres, as listed in **Table 6-1**. Cost effects and total machinery savings potential are as stated for cutting processes in Task 5 (measures are numbered as in Task 5 as well)[2]. Some of the options are distinct measures, whereas others are open to a combination of several measures, see e.g. option 9, Combination of several hydraulic system related measures: In this case it is estimated, that with a proper selection of hydraulics-related measures, usually an improvement of 3% should be possible with at an additional 5% purchase cost investment in machinery.

A correction factor is introduced to reflect the fact that all measures are already implemented in a certain market share. Thus, neither the savings potential, nor the cost increase should be applied to all machine tools covered by this Base Case, but only to the remaining market share[3].

Table 6-1: Design Options for Base Case 1

Measure	**Cost effects (investment) Increase in total machinery invest (tendency)**	**Total machinery savings potential (tendency)**	**Market share**	
			in currently sold machine tools	Correction factor to consider already achieved market penetration
Option 1				
10.3 Minimise non-productive time	0%	5%	46%	0,54
Option 2				
2.8 400V inverter systems to substitute 200V systems	0%	1%	76%	0,24
Option 3				
2.1 Regenerative feedback of Inverter system (servo motor/spindle)	0%	0,5%	76%	0,24
Option 4				
8.1 Controlled peripheral devices like mist extraction, chip conveyer, etc	0,2%	1%	36%	0,74
Option 5				
7.10 Single master switch-off	1%	1%	53%	0,47

2 This data is based on the 2011 survey data, but notice that later 2012 updates indicate a lower savings potential for some of the measures. However, as our analysis and aggregation followed a rather conservative approach and takes a lower potential in case of a large spread of replies, this uncertainty is already factored in. Furthermore, none of the stakeholder comments received challenged the estimates given in Table 6-1.

3 This approach and correction factor however neglects that certain options might not be relevant for a certain machine tool at all, and thus 100% market share is practically impossible in some cases.

Option 6						
Combination of several power electronics related measures						
6.2 High efficiency transformer	1%	2%	0,5%	1,5%	23%	0,5
6.3 Converter with power factor correction	1%		0,5%		29%	
6.4 Controlled switching power supply for auxiliary power 24V	0,2%		0,5%		77%	
Option 7						
Combination of several cooling lubrication system related measures						
4.1 Discontinuous operating pumps	0,2 %	3%	0,5%	2%	31%	0,6
4.3 Adjustable pressure for cooling lubrication	1%		0,5%		48%	
4.4 Controlled flow rate	1%		1%		44%	
4.5 Inverter controlled motors for lubrication system	1%		0,5%		37%	
Option 8						
Combination of several overall machine related measures						
1.2 reduction of friction	1%	3%	0,5%	2%	53%	0,6
1.3 optimization of the electrical design	1%		1%		43%	
1.4 design for instant machining without warm up	1%		1%		33%	
Option 9						
Combination of several hydraulic system related measures						
3.1 Discontinouous operating pumps	1%	5%	1%	3%	38%	0,65
3.2 Speed controlled pumps	1%		1%		22%	
3.3 Optimize hydraulic system design	n.a.		0,5%		35%	
3.4 Optimized piping	1%		0,5%		33%	
3.5 Fixed orifice blades to control the system pressure	1%		0,5%		46%	
3.6 Leakage monitoring	1%		0,5%		30%	
3.7 Use of hydraulic system with optimized components	n.a.		0,5%		20%	
Option 10						
Combination of several drive units related measures						
2.2 Use of energy efficient motors for auxiliary units	3%	10%	1%	3%	44%	0,5
2.3 Use of torque motors	1%		1%		37%	
2.4 High efficient gear unit	0,2%		0,5%		32%	
2.5 Mass free compensation of load for vertical axes	3%		1%		55%	
2.6 Use of break to control movement of axes	3%		0,5%		34%	
2.7 Inverter controlled motors for auxiliary units	5%		1%		30%	
Option 11						
7.9 Optimised compressed air system with minimal losses	3%		1%		38%	0,62

Option 12				
7.11 Individual switched-off capability for specific modules	3%	1%	50%	0,5
Option 13				
7.5 Multi spindle-/ multi workpieces machining	>3%	5%	36%	0,64
Option 14				
7.7 Combination of various technologies (turning + milling + laser + grinding etc.)	>3%	5%	31%	0,69

This list does not include measures, which are an alternative option to those already listed here (e.g. 6.1 Avoidance of transformers... is an alternative measure to 6.2 High efficiency transformers...). In these cases only the option is listed, which is likely to have the better effect at lower costs. Furthermore, simplification measures are not listed here, for which very high implementation costs have been stated, which constitute a basically changed processing concept (e.g. Minimum Quantity Lubrication), or for which a broad span of implementation costs have been stated. When interpreting the assessments based on this list it is therefore important to keep in mind, that:

- estimates regarding costs and savings from the various respondents have been merged with a rather conservative approach, i.e. costs where a larger spread is appropriate are averaged with a rather higher value, and efficiency gains are given a lower value
- there are many more measures to achieve similar savings, which means that vice visa the above list cannot be considered as a recommended list of options to be implemented, as this depends on application and specific design.

For comparison, **Table 6-2** provides a summary of improvement potentials explored for various CNC machine tools within an eco-design project in the Basque country[4], applying a Life Cycle Analysis, followed by checking the feasibility of implementing numerous eco-design options. The analysis unveils, that for a given “real world” machine tool, there are typically numerous measures which could be applied, but most of these typically each result in minor improvements, together totalling significant savings. The range of improvements which could be realised is immense, and varies between 1,8% and 48% of the total life cycle impacts. These examples illustrate that it is not justifiable to state a “general” improvement potential..

Table 6-2: Examples of Optimisation Measures Applied for CNC Machine Tools

[4] For details, see: IHOBE: Guías sectoriales de ecodiseño – Máquina herramienta, February 2010

Measure	Goratu Movable Milling Machine GMM	Danobat Turning Machine Tool NA-500/GL	Tornos Gurutzpe Horizontal Machining Tool	Fagor Mechanical Press SDM2-400-2400-1200	Onapres Hydraulic Press EVT-225-4,6-AS
Measure	Total Life Cycle Impacts Reduction				
Reduce standby	-1%	-0,8%	-2,3%		
Replace steel foundation by polymer concrete		< 1%	-0,6%		
Burnishing for surface treatment			-1%		
Biodegradable lubricants			-0,3%		
Water-based painting, organic-solvent free			-0,4%		<<1%
Recuperation of energy				-30%	
Synchronising the process throughout the line (reduced standby time)				-2%	
Use of direct servo-drives				-12%	
Lubrication oil mist extraction and reuse				-2%	
Use of lightweight material / reduce weight of moving parts				-2%	-1%
Implementation energy management system (whole line)					-30%
(External) reuse of heat generated at the stamping process					(external)
Condition monitoring / predictive maintenance		relevant, but not quantified			
Optimized extraction system	-0,4%				
Optimized noise insulation material	-0,1%				
Implementing multiple processes (milling and turning)	-12,6%[5]				
Total	**-14,1%**	**-1,8%**	**-4,6%**	**-48%**	**-31%**

[5] Related to installed total connected load

6.1.1.2 Base Case 2 - Laser cutting machine tools

For laser cutting machine tools (Base Case 2) the above stated savings potentials are not directly applicable as the energy consumption profile looks completely different, and is dominated by the laser source, followed by the chiller unit (see task 4, 4.1.3.2). Some studies have identified fibre laser sources as the more energy efficient technology compared to the more conventional CO2 lasers. The overall energy efficiency of CO2 lasers is stated to be at roughly 10% compared to 30% for fibre lasers, basically due to the physics of the technology. This results in some comparisons where fibre lasers are recommended over CO2 lasers[6,7]. The analysis by Devoldere et al. refers to processing of 1mm thick steel sheets. Energy consumption (electricity only) figures are listed in **Table 6-3**.

Table 6-3: Comparison CO2 laser and fibre laser processing (Devoldere et al.)

Laser type[8]	CO2	fibre	CO2	fibre	CO2	fibre
Shifts (@ 8h/day, 250 days/a)	**1**		**2**		**3**	
Occupation rate	84,9% of total production time					
Power consumption per mode per year (kWh)						
Off mode[9]	11.889	0	8.372	0	4.854	0
Start-up	1.400	1.400	1.400	1.400	280	280
Production (@5kW laser output)	80.825	64.184	161.650	128.369	242.474	192.553
Move table	3.686	3.661	7.373	7.322	11.059	10.982
Stand-by	5.158	3.993	10.315	7.986	15.473	11.979
Total kWh	**102.958**	**73.238**	**189.109**	**145.076**	**274.140**	**215.794**

6 Devoldere, T.; Dewulf, W.; Deprez, W.; Duflou, J.R.: Energy Related Life Cycle Impact and Cost Reduction Opportunities in Machine Design: The Laser Cutting Case, Proc. 15th CIRP International Conference on Life Cycle Engineering, Sydney, Australia, ISBN 1-877040-67-3. pp. 412-419.

7 Oliveira, M.; Santos, J.P.; Almeida, F.G.; Reis, A.; Pereira, J.P.; Rocha, A.B.: Impact of Laser-Based Technologies in the Energy-Consumption of Metal Cutters: Comparison between Commercially Available Systems, Journal Key Engineering Materials, Vol. 473, 2011, pp. 809-815

8 CO2: model LVD Axel 3015 S; fibre: hypothetical configuration

9 CO2 laser assumed to be in „winter off“ during 4 month, with higher chiller power consumption

A similar analysis was undertaken by Oliveira et al. [10], comparing the processing of a 1 mm carbon steel sheet for 1 hour with a 4,5 kW CO2 laser, a 2,5 kW CO2 laser and a 2,0 kW fibre laser. The latter features significantly lower power consumption.

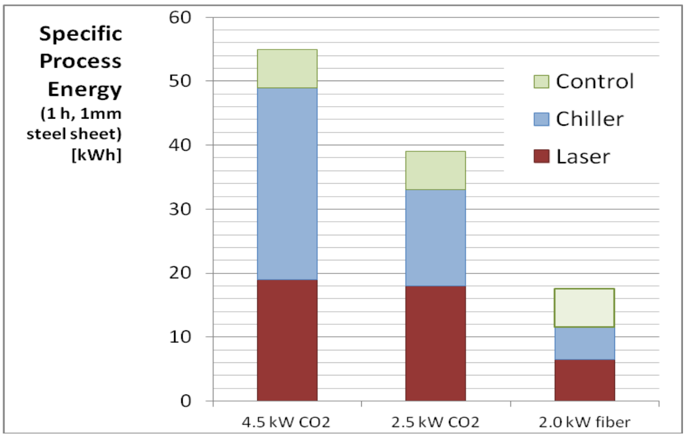

Figure 6-1: Specific Process Energy for Laser Cutting (adapted from Oliveira et. al[11])

Another technical comparison is provided in **Table 6-4** for 3kW laser systems[12].

Table 6-4: Comparison CO2 laser and fibre laser processing (statements by Laser Photonics)

	CO2 Laser (3000W)	Fibre Laser (3000W)
Reliability (MTBF)	Only around 20,000 hours	50,000 to 100,000 hours
Electrical Power Requirements	Laser Consumption: 54 kW Chiller Consumption: 32 kW (Estimate)	Laser Consumption: 14 kW Chiller Consumption: 11kW (Estimate)
Maintenance	Estimated Purge Gas Consumables: Nitrogen, Carbon Dioxide, Helium Estimated Gas Cost: $7.66/h	Minimum Maintenance Low Consumables No cleaning of or alignment of mirrors for beam path
Power Efficiency	6-7%	Greater than 30%
Cooling	50,000 BTU	10,000 BTU

10 Oliveira, M.; Santos, J.P.; Almeida, F.G.; Reis, A.; Pereira, J.P.; Rocha, A.B.: Impact of Laser-Based Technologies in the Energy-Consumption of Metal Cutters: Comparison between Commercially Available Systems, Journal Key Engineering Materials, Vol. 473, 2011, pp. 809-815

11 Data for control unit of the fibre laser set equal with the control units of CO2 lasers, as observed differences are not technology related according to Oliveira et al.

12 http://www.laserphotonics.com/products/fiber-cutting-series/fiber-vs-co2-comparison

A more balanced technical comparison is provided in **Table 6-5**, outlining pros and cons of both technologies, based on industry sources. Actually it is evident, that the field of application for both systems overlaps when considering steel and aluminium sheets up to 4-5 mm, which is an important market segment, and here solid state fibre lasers are the (environmentally) better option, but are not suitable for thicker sheets, and therefore limit the flexibility of using fibre lasers in machinery. As companies, in particular contract manufacturers, might change their production portfolio over time, fibre lasers can therefore not be recommended as a general "blanket" improvement option. The improvement option could be instead to provide sound customer information about pros and cons, and likely costs and energy effects of both technologies, allowing customers to make a choice regarding which technology fits best to their production strategy, and to choose fibre lasers if suitable.

The potential of a further change from CO2 to fibre lasers has to consider the current market share of technologies. In 2008 the global market share of CO2 lasers for material processing was 37%, and for solid state lasers 43% (thereof 7% fibre and 36% rod and disk). The remaining 20% are mainly excimer lasers (for e.g. photolithography)[13]. Although highly speculative in absence of reliable data, a calculated improvement option in the next section is that 10% of the laser cutting machines represented by Base Case 2 are fibre lasers instead of CO2 lasers, this option occurring due to an informed decision by machine tools users[14]. This option is calculated with 25% lower energy consumption[15] for this 10% portion of the market.

Table 6-5: Technical and Performance Comparison CO2 Laser and Fibre Laser processing

	CO2 Laser	Fibre Laser / Solid State Laser
Cutting velocities	Faster than Fibre lasers in materials thicker than 5mm as the laser can be absorbed better at higher levels of incidence	Faster than CO2 lasers in thin materials, due to higher absorption coefficient of most metals
Quality	Quality is consistent throughout all thicknesses of material; from a sheet	comparable up to 5mm; the thicker the sheet, the rougher the edges;

[13] Mayer, A.: Economic Downturn Hits Laser Market at Record High, Laser Technik Journal, Vol. 6, Issue 3, May 2009

[14] An assumption of 10% is not based on any insights in likely changes, but is rather meant to allow an estimate of the effect of a change in this order of magnitude

[15] Based on the exemplary investigations stated above – but notice, that these 25% are only realistic for certain applications, and in no way should lead to the simplified statement that fiber lasers are better than CO2 lasers per se

	thickness of about 4 mm cut quality is better than with fibre lasers	higher focussing ability/ reduced kerf size
Flexibility	High, suitable for all material thicknesses	Low regarding sheet thickness, only suitable for materials up to 5mm in thickness
Materials	Well suited for construction steel, stainless steel and aluminium, but not for copper	Well suited for construction steel, stainless steel and aluminium, non-ferrous metals such as copper and brass
Cost per part	Higher for sheet thickness up to 5 mm	less than the CO2 laser, up to 5mm in sheet thickness; rougher edges might require an additional deburring process
Safety	CO2 laser light (10µm) is absorbed by the cornea (no risk of irreparable damage to the retina)	Strict safety precautions must be taken as the laser can pass straight through to the eye's retina
Beam guidance	mirror optics	fibre optics (advantageous compared to alignment of mirrors), one laser source could feed several cutting machines

Efficient chiller units can save a significant share of power consumption in use[16], which includes efficient components for compressors, an adapted power management (switch on and off of compressors as needed, see also power consumption profiles for laser cutting machine tools in Task 4), or alternatively an interface to a central cooling system, which might allow heat recovery from the chiller. This effect is calculated as option 2 with a conservative savings potential of 5% energy consumption (which actually might be realised externally to the machine, not internally)[17].

It should be noted that no benchmark for laser cutting machine tools is available, neither to this study's authors, nor does it seem that such data is available to machine tools manufacturers. Hence, achievable savings potentials beyond the above stated assumptions cannot be verified. It can be anticipated that several of the improvement options stated for CNC machine tools are applicable to laser cutting machine tools as well, but given the major difference in machine construction and power consumption profiles no estimate could be made, regarding which savings could be realised, at which costs. According to industry experts, further improvement potentials for laser cutting machine tools are rather marginal.

16 See e.g.: TRUMPF: Ressourceneffizienz – Nachhaltig denken – effizient handeln, brochure

17 Default correction factor 0,5

6.1.1.3 CNC Metal working bending machine tools

Based on the estimates regarding improvement potentials and related cost effects stated in the Task 5 report for hydraulic presses, a consecutive implementation of options has to be modelled[18]. An order of options established for CNC metal working bending machine tools is listed in **Table 6-6**. Cost effects and total machinery savings potential are as stated for hydraulic presses in Task 5 (measures are numbered as in task 5 as well). Some of the options are distinct measures, whereas others are open to a combination of several components, see e.g. option 14, Combination of several control related measures.

A correction factor is introduced to reflect the fact, that all measures are already implemented in a certain market share, thus neither the savings potential, nor the cost increase should be applied to all machine tools covered by this Base Case, but only to the remaining market share.

Table 6-6: Design Options for Base Case 3

ISO 14955 table B1	Measure	Cost effects (investment) Increase in total machinery invest (tendency)	Total machinery savings potential (tendency)	Market share (hydraulic presses)	
				in currently sold machine tools	Correction factor to consider already achieved market penetration
Option 1					
9.3	Provide customer information to reduce consumption of resources	0%	1%	20%	0,8
Option 2					
3.4.1	Energy efficient pulse valves	0%	0,5%	10%	0,9
Option 3					
9.1	Optimisation of work piece processing by die tryout	0%	0,5%	60%	0,4
Option 4					
3.3.2	Avoid internal leakage	0%	0,5%	70%	0,3
Option 5					

18 The survey yielded two replies for hydraulic presses and one reply for servo presses. As a direct comparison of both technologies is not intended (as the different fields of application have to be considered for such an analysis), and as the improvement options are different for both technologies, only the replies for hydraulic presses have been considered here.

3.1.1	Choice of the pump systems which match the requirement profile	0%		1%		95%	0,05
Option 6							
8.1	Controlled peripheral devices like mist extraction, scrap conveyer, etc	0%		0,5%		90%	0,1
Option 7							
7.2.2	Directed switch off of not needed branches	0%		0,5%		90%	0,1
Option 8							
4.2	Low flow rate for lubrication pump	0%		0,5%		90%	0,1
Option 9							
6.3	Apply the simultaneity factor when designing the power system	0%		0,5%		90%	0,1
Option 10							
1.1	Minimisation of moved masses	0%		1%		95%	0,05
Option 11							
1.3	Optimization of the overall machine design	0%		0,5%		90%	0,1
Option 12							
2.4	Use of energy efficient motors	0,2%		1%		55%	0,45
Option 13							
3.2	Match the pressure level to the load cycle and to the different actuators on the machine	0,2%		1%		80%	0,2
Option 14							
Combination of several control related measures							
10.2	Automatic operating state switching	0,2%	0,4%	0,5%	1%	<1%	1,0
10.3	Recording of current energy consumption together with energy relevant production data	0,2%		0,5%		0%	
Option 15							
Combination of several pneumatic system related measures							
7.1	Switching valves with low Watt technology, pulse width modulation (PWM), valves with detent (where permissible)	0,2%	1,0%	0,5%	2,5%	20%	0,3
7.2.1	Reduction of dead volume (Vcut)	0,2%		0,5%		80%	
7.2.4	Correct layout of pneumatic drives	0,2%		0,5%		80%	
7.2.5	Reduction of pressure	0,2%		0,5%		70%	
7.2.7	Optimise cylinder force for the required function	0,2%		1%		90%	
Option 16							
3.4.2	Energy efficient valve connectors	0,2%		0,5%		0%	1,0
Option 17							
3.2.4	Use of pressure intensifiers for individual actuators which require higher pressure	0,2%		0,5%		20%	0,8
Option 18							
4.1	Lubrication flow depending on demand	0,2%		0,5%		60%	0,4
Option 19							
Any of the following:							

2.8	Direct coupled energy storing drive systems for main drives	5%	5%	5%	5%	8%	1,0
2.9	Indirect coupled energy storing drive systems for main drives	5%		5%		0%	
2.10	Intelligent drive management	3%		3%		5%	
Option 20							
3.2.3	Pressure adjustment using pressure-controlled drive systems	5%		5%		53%	0,47
Option 21							
3.3.1	Displacement control systems	3%		3%		65%	0,35
Option 22							
2.6	Use of multi-pressure accumulator system for main axis	5%		5%		3%	0,97

This list does not include measures, which are an alternative option to those already listed here. In these cases only the option is listed, which is likely to have the better effect at lower costs. Furthermore, for simplification measures are not listed here, for which very high implementation costs have been stated, which constitute a basically changed processing concept or for which a broad span of implementation costs have been stated.

6.1.1.4 Base Case 4 - Non-numerical controlled metal working machine tools

As distinct from CNC metalworking machines and laser cutting machines, non-numerical metal working machines tool are less complex and feature a smaller number of modules. Additionally, due to a low extent of operating hours per year, which is in the area of around 1500 hours per year (see task 4, 4.1.3.4), some improvement options do not pay off, as the anticipated life cycle costs of such actions are not proportionate with the expected benefit, such as energy monitoring devices. In reference to identified BATs in Task 5 a check-up between potential solutions and its feasibility for implementation in non-numerical machine tools are assessed, see **Table 6-7**. The table reveals a lack of research and opportunities to raise the eco-efficiency of such machines, which corresponds with the fact that they consume a lot less energy than CNC machines, for which a broad set of implementation opportunities deriving from the BATs are provided.

Table 6-7: Suitability of BATs for non-numerical controlled metal working machine tools - screening

Solution	Suitability for non-numerical controlled metal working machine tools
Mass Reduction of Moving Parts	Marginally suitable, too few operating hours to compensate additional costs
Software-based Energy Management including Stand-By Mode	Marginally suitable, too few operating hours to compensate additional costs

Energy Recuperation of Drives, Power Electronics, Super Premium Efficiency Motors	Marginally suitable in regard to energy recuperation, too few start and stop motions, too few drives (in range of 1-2 drives per machine); suitable in regard to efficient motors
Tool Handling and Clamping	Not suitable, too few operating hours to compensate additional costs; operations usually do not require sophisticated tool handling and clamping solutions
Hydraulic and Pneumatic Optimized Systems	Marginally suitable, in general pneumatic and hydraulic systems rarely found in non-numerical controlled machine tools; too few operating hours to compensate additional costs
Energy-Efficient Cooling Lubricant Supply	Not suitable, in general lubrication system rarely found
Cooling Systems and Use of Cabinet Heat	Not suitable, in general cabinets not necessary, generation of heat during process is negligible
Energy-efficient Tempering	Not suitable, process accuracy does not require tempering (cutting), too few operating hours to compensate additional costs (forming)
Productivity and processing time	Not suitable, sophisticated productivity targets not followed by using non-numerical controlled machines

Just to name a dedicated example, **regenerative drives** are usually not suitable for non-NC machine tools, as the path required for returning the energy and the related power electronics components generate additional losses, which leads to even higher power consumption with regenerative drives. Automatic, frequent tool change (i.e. braking), which is common for CNC machine tools does not happen in the case of non-NC machine tools typically (see task 5, 5.1.4.1).

Motors as the dominating component with respect to energy consumption remain the only subject for relevant improvement options. However, motors typically used in non-NC machine tools are already regulated by Commission Regulation (EC) No 640/2009 on ecodesign requirements for electric motors, and have had to meet the IE2 efficiency level since June 2011, followed by more stringent requirements to follow in 2015 and 2017, respectively. With these electric motor requirements, significant improvements are already underway, compared in particular to the stock of older non-NC machine tools, and the only remaining option is to encouragethe speedy replacement of this old stock by the new, more efficient generateon of machinery. As a technical option, an early implementation of IE3 motors (which are readily available) instead of IE2 is calculated: Compared to IE2 an IE3 motor (5.5 kW P_N, 4 poles, 50 Hz) has to meet an energy efficiency of 89,6%, instead of 87,7%, which means nearly an energy saving of 2,2%. According to IEC 60034-31:2009 “the typical price increase could be between 10% to 30% per efficiency class improvement”. Anticipating that an IE2 motor in the power range relevant for non-NC machine tools costs maximum €500, an IE3 motor increases the total purchase price of a non-NC machine tool as a worst-case assumption by €150 (option 1).

6.1.2 Wood working machine tools

6.1.2.1 Base Case 5 - Light-stationary machine tools

Given their limited complexity, the possibility for improvements is limited regarding light-stationary wood working tools, as reflected by the Base Case 5 Table saw..

Among small wood working machine tools machine tables made of aluminium are frequently used. An alternative are machine tables made of cast iron instead of aluminium (option 1), as (primary) iron has a smaller environmental impact than (primary) aluminium. However, iron adds weight to the machine tool, which might be less relevant for e.g. radial arm saws, which are used stationary in workshops, but severely impacts user-friendliness in case of small machine tools, which are used at changing locations, i.e. construction sites, where low weight is important. There is no direct cost comparison available, comparing a machine table made of cast iron with aluminium, but generally speaking, based on evidence from the automotive sector, aluminium alloys are more costly than the currently used steel and cast irons that they might replace. Nevertheless, compared to cast iron and steel, cast aluminium components are potentially less costly due to reduced manufacturing cycle times, as – among some other advantages - machinability is enhanced, and they are more easily produced to near net shape. Contrary to cast parts, wrought aluminium and magnesium components are almost always more costly to produce than their ferrous counterparts.[19] In our analysis, no cost difference is applied, in the absence of a dedicated comparative case.[20]

Based on an input by EPTA there is technically the option of higher motor efficiencies[21]. This is calculated with an energy savings potential of 5%, meaning a power consumption in active mode of 0,95 kWh at 73,7% motor efficiency (option 2), instead of 1 kWh at 70% as stated by EPTA as the current status of sold units.

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[19] Ghassemieh, E.: Materials in Automotive Application, State of the Art and Prospects; in: New Trends and Developments in Automotive Industry, Edited by: Marcello Chiaberge, Publisher: InTech, January 2011, ISBN 978-953-307-999-8

[20] But it should be noted, that EPTA raised severe doubts in a stakeholder comment, that cost neutrality applies

[21] motor efficiency is currently the subject of ErP Lot 30 preparatory study and motors for these products are expected to be in scope

These improvements according to EPTA could be realised through following measures, but at a higher purchase price of estimated 25 Euros and additional material consumption[22]:

- Reduce the lamination leakage[23]
- Optimise the airflow
- Choose the best raw material for winding
- Optimise the winding
- Optimise the motor surface

6.1.2.2 Base Cases 6, 7 & 8 - Large wood working machine tools

Larger crafts and industry-use wood working machine tools are covered by three Base cases in Task 4: Horizontal panel saw (Base Case 6), Throughfeed edge banding machine (Base Case 7) and CNC machining center (Base Case 8).

Based on the estimates regarding improvement potentials and related cost effects stated in the Task 5 report, a consecutive implementation of options has to be modelled. According to the methodology for preparatory studies, the implementation of options has to start with those environmental improvements, which feature the highest decrease of life cycle costs, followed by those measures, which further reduce environmental impacts, but at higher life cycle costs. With this approach an order of options is established as listed in **Table 6-8**, but not all of them are applicable for all three of the Base Cases 6, 7 & 8. Cost effects and total machinery savings potential are as stated for cutting processes in Task 5 (measures are numbered as in Task 5 as well). As no dedicated feedback on market penetration of certain options was provided by stakeholders, a default value of 50% market penetration is applied, except for option 6, Minimized pre-heated glue volume, where a correction factor of 0,1 is applied as the Base Case 7. The Throughfeed edge banding machine is meant to be representative

[22] Approximated with additional 2,15 kg copper winding wire, corresponding to an environmental impact as stated by EPTA (the related LCA study was not accessible to Fraunhofer, but correlations are plausible)

[23] Power stray losses caused by the design of transformer cores (stacking layers of thin steel laminations)

for more market segments than solely those applying glue to edges (see Task 4 for market coverage).

Table 6-8: Design Options for Base Cases 6 - 8

<table>
<tr><th rowspan="2">Measure</th><th colspan="2" rowspan="2">Cost effects (investment)
Increase in total machinery invest (tendency)</th><th colspan="2" rowspan="2">Total machinery energy savings potential (tendency)</th><th colspan="3">Base Case relevancy and default correction factor for market penetration</th></tr>
<tr><th>BC 6: Horizontal panel saw</th><th>BC 7: Through-feed edge banding machine</th><th>BC 8: CNC wood working machining center</th></tr>
<tr><td colspan="8">Option 1</td></tr>
<tr><td>3.1 Application-specific design of drives</td><td colspan="2">0%</td><td colspan="2">1%</td><td>0,5</td><td>0,5</td><td>0,5</td></tr>
<tr><td colspan="8">Option 2</td></tr>
<tr><td>2.2 Machine stand-by management</td><td colspan="2">0,2%</td><td colspan="2">5%</td><td>0,5</td><td>0,5</td><td>0,5</td></tr>
<tr><td colspan="8">Option 3</td></tr>
<tr><td>1.3 Less parts to be moved</td><td colspan="2">0,2%</td><td colspan="2">1%</td><td>0,5</td><td>n.a.</td><td>n.a.</td></tr>
<tr><td colspan="8">Option 4</td></tr>
<tr><td>4.1 Electrical clamping devices</td><td>1%</td><td rowspan="10">1%</td><td>3%</td><td rowspan="10">1%</td><td rowspan="10">n.a.</td><td rowspan="10">n.a.</td><td rowspan="10">0,5</td></tr>
<tr><td>or a combination of:</td><td></td><td></td></tr>
<tr><td>5.12 Reducing channels of supply / dead volume</td><td>0,2%</td><td>1%</td></tr>
<tr><td>5.13 Minimizing losses due to leakages (pneumatics)</td><td>0,2%</td><td>1%</td></tr>
<tr><td>5.14 Pneumatic Cylinder with optimized drive surface</td><td>0,2%</td><td>1%</td></tr>
<tr><td>5.15 Pneumatic Cylinder with multiple chambers</td><td></td><td>0,5%</td></tr>
<tr><td>5.16 Single acting pneumatic cylinder</td><td>0,2%</td><td>1%</td></tr>
<tr><td>5.17 Targeted cut-off from air supply</td><td>0,2%</td><td>1%</td></tr>
<tr><td>5.18 Use of multiple valves</td><td>0,2%</td><td>0,5%</td></tr>
<tr><td>5.19 Pressure reduction</td><td>0,2%</td><td>1%</td></tr>
<tr><td colspan="8">Option 5</td></tr>
<tr><td>5.24 Optimised blowing nozzles</td><td colspan="2">0,2%</td><td colspan="2">1%</td><td>0,5</td><td>0,5</td><td>0,5</td></tr>
<tr><td colspan="8">Option 6</td></tr>
<tr><td>-.- Minimized pre-heated glue volume</td><td colspan="2">2,5%</td><td colspan="2">10%</td><td>n.a.</td><td>0,1</td><td>n.a.</td></tr>
<tr><td colspan="8">Option 7</td></tr>
<tr><td colspan="8">Combination of measures for improved electronics / power supply</td></tr>
<tr><td>3.6 Reducing transmission losses</td><td>0,2%</td><td>0,6%</td><td>0,5%</td><td>1,5%</td><td>0,5</td><td>0,5</td><td>0,5</td></tr>
</table>

3.7 Replacing inverter units / 400 V instead of 200 V	0,2%	0,5%			
3.9 Avoidance of transformers	0,2%	0,5%			
Option 8					
5.25 load-dependent air table control	1%	1%	0,5	n.a.	n.a.
Option 9					
2.1 Energy monitoring	1%	1%	0,5	0,5	0,5
Option 10					
3.13 efficient motors also <750 W	1%	1%	0,5	0,5	0,5
Option 11					
5.28 line-controlled blow-off device to adapt air consumption to actual needs	1%	1%	n.a.	n.a.	0,5

This list does not include measures which are an alternative option to those already listed here. In these cases, the only option listed is that which is likely to have the better effect at lower costs. Furthermore, for simplification, measures are not listed here, for which very high implementation costs are assumed, or which constitute basically a process-changing concept.

6.1.3 Base Case 9 - Welding equipment

For welding equipment, three distinct options have been identified on the general level represented by the Base Case:

Option 1: Arc welding DC Power source efficiency 85% instead of an average 75% (weighted stock average as stated in task 4, 4.1.3.9)[24].

Option 2: No analysis is available regarding the shielding gas savings potential, overall. As some sources indicate a significant savings potential (see task 5, 5.1.10.3), this study calculates with **a 10% gas saving through a combination of state-of-the-art measures** (increasing the purchase price by 20% as a conservative estimate).

Option 3: Idle power consumption of less than 10 W is achievable when the fan has automatically stopped, and is realised for e.g. stud welding equipment. It might be required that thorough power management is implemented, which switches the welding equipment to such a sleep mode (see task 5, 5.1.10.1). Whereas in larger industrial units this feature does not add significantly to product costs, it might be significant for

[24] In the draft task 6 report option 1 was based on a power source efficiency of 90% initially, which was considered BNAT by EWA and not a feasible option as of today.

smaller, simpler units, but data is missing to substantiate this aspect. However, long-term costs for related power electronics circuitries and components will drop further.

There is much more potential for increasing the efficiency of welding, but this is related to the right choice of welding technology and welding gas for the intended application. This is a matter of thorough process planning, welder education and information, but not of welding equipment design as such. Therefore this option is not taken into account here to avoid the impression, that a certain technology could be replaced completely by another. Such a choice always has to consider the intended application.

6.2 Analysis BAT and LLCC

The objective is to identify, amongst the options analysed, the Least Life Cycle Cost (LLCC) option and the Best Available Technology (BAT).

This task includes as a general approach, following MEEuP:

- Ranking of the individual design options by LCC (e.g. option 1, 2, 3, compared to the Base Case), see **Figure 6-2**.

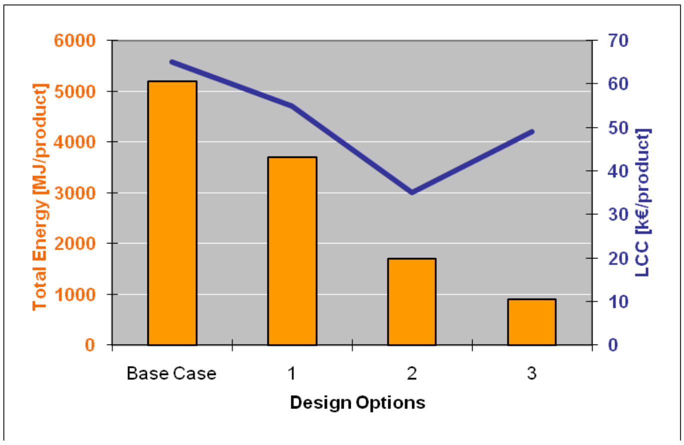

Figure 6-2: Methodological Approach: Base Case in Comparison with Design Options

- Estimation of the accumulative improvement and cost effect of implementing the ranked options simultaneously (e.g. option 1, option 1+2, option 1+2+3, etc.), also taking into account the above possible side-effects
    - Here, the only options which will be considered are those which can be applied in a cumulative manner.

  - In some cases, simply adding the cost and benefits/impacts of the different options will not be relevant, and in fact might generate double counting, or underestimate some scale effects.

- Ranking of the cumulative design options, drawing a LCC-curve and identifying the Least Life Cycle Cost (LLCC) point and the point with the Best Available Technology (BAT), see **Figure 6-3**, illustratively.

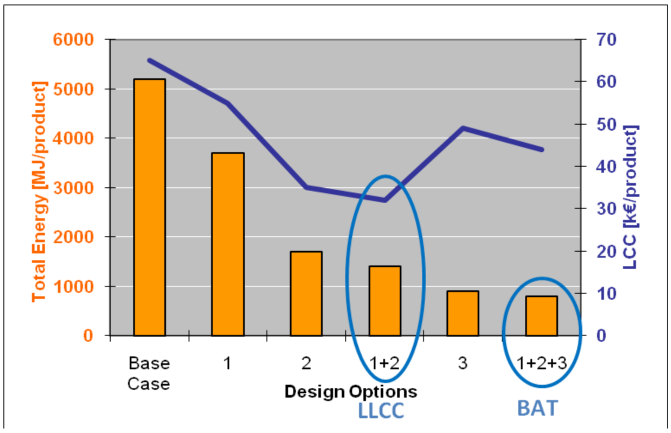

Figure 6-3: Methodological Approach: Identifying LLCC and BAT

It might also be the case, that one combination of improvement options indicates the point of LLCC for one market segment (i.e. base case improvement), but a different combination for another market segment.

6.2.1 Base Case 1: CNC 4-axis multifunctional milling centre

Improvement options listed in **Table 6-1** are analysed as follows: The base case assessment from Task 4 is adjusted now by the investment cost changes and energy savings in the use phase, each considering the correction factor. Option 2 includes option 1, option 3 includes option 1 and 2, and so forth. For each consecutive option the cost increase as a share of the initial machinery cost is added (which neglects the fact, that a combined implementation might be less costly, than only the addition of two measures):

$$C_{invest,i} = C_{invest,BC} \cdot (1 + \sum_{n=1}^{i} c_n \cdot cf_n)$$

The purchase price C_{invest} of a machine tool for a given option i is calculated as the initial purchase price $C_{invest,BC}$ for the base case, multiplied by one and the sum of cost increase c_n (as decimal figure) for each option n=1 to i multiplied by the correction factor cf_n.

Contrary to the costs, the energy savings are not just aggregated, but for each option the point of reference for further savings is the energy consumption level achieved with the option before:

$$E_i = E_{BC} \cdot \prod_{n=1}^{i} (1 - e_n \cdot cf_n)$$

Use phase energy consumption E for any option i is calculated as the Base Case energy consumption E_{BC} multiplied by the product of 1 minus energy reduction e_n (in decimal figures) times correction factor cf_n for each option n.

Options 13 (multi-spindle / multi workpieces machining) and 14 (combination of various technologies, turning / milling / laser / grinding etc.) are depicted here as well for comparison, but these involve major changes of the machinery concept as such. Whereas these options can be highly relevant for manufacturing a high number of uniform, complex products, this might result in even increasing environmental impacts, if machine tools are "oversized" for rather simple applications.

The resulting curve of Life Cycle Costs and Total Energy for Base Case 1 is depicted in **Figure 6-4**. Total Energy is chosen as the key unit indicator. For the other environmental unit indicators see **Table 6-9**, but these run largely in parallel with the indicator Total Energy.

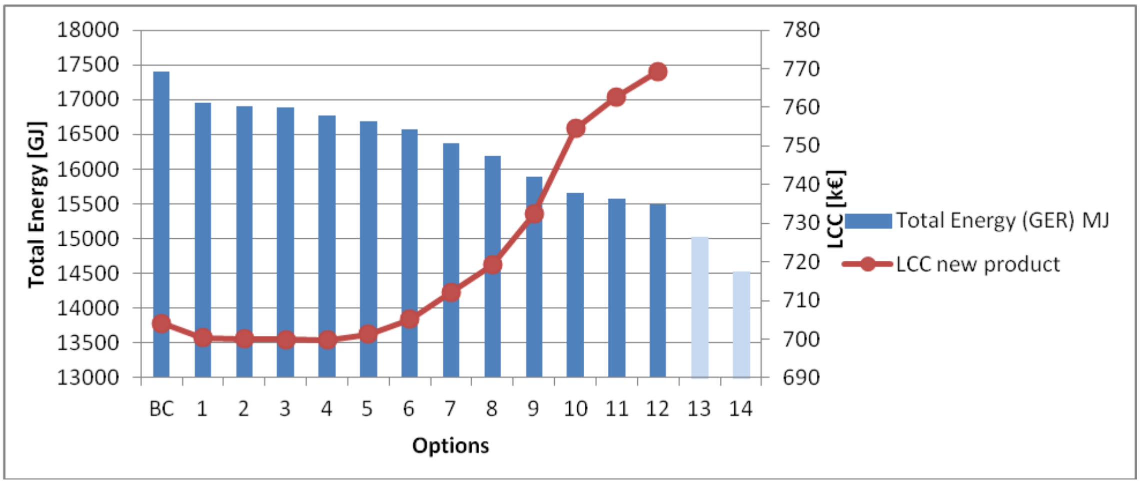

Figure 6-4: Base Case 1 – Total Energy and LCC per Option

The point of Least Life Cycle Costs is option 4 (including consecutive implementation of options 1-3). The point of Least Life Cycle Costs is only marginally lower than the Life Cycle Costs of the initial Base Case, namely 0.6%, at nearly 4% Total Energy savings over lifetime. All other options result in increasing Life Cycle Costs as the energy savings are not compensated by the additional initial investment. However, this statement holds true only for such a very general analysis. The replies received from manufacturers indicate, that for specific machine tools or market segments there are significant savings potentials at low or moderate costs, but this has to be assessed carefully on a case-by-case basis and cannot be stated as a general finding.

Table 6-9: Improvements for Base Case 1 (one product, full life cycle, life cycle costs)

				Option														
	Other Resources & Waste		BC	1	2	3	4	5	6	7	8	9	10	11	12	13	14
8	Total Energy (GER) MJ	MJ	17400660	16949075	16910018	16890568	16773263	16694976	16572442	16379184	16191904	15888258	15661538	15568309	15492036	15019771	14525142
9	of which, electricity (in primary MJ)	MJ	16817509	16365925	16326867	16307417	16190113	16111825	15989292	15796033	15608754	15305108	15078387	14985159	14908886	14436620	13941991
10	Water (process)	ltr	1370986	1340880	1338276	1336980	1329159	1323940	1315771	1302887	1290402	1270159	1255044	1248829	1243744	1212260	1179285
11	Water (cooling)	ltr	44687823	43483596	43379444	43327576	43014765	42805998	42479243	41963886	41464474	40654752	40050163	39801554	39598160	38338785	37019774
12	Waste, non-haz./ landfill	g	46953141	46429554	46384269	46361718	46225710	46134940	45992870	45768797	45551657	45199597	44936727	44828634	44740200	44192635	43619141
13	Waste, hazardous/ incinerated	g	420434	410027,7	409128	408680	405976	404173	401349	396896	392580	385583	380359,1	378211	376453	365571	354173
	Emissions (Air)																
14	Greenhouse Gases in GWP100	kg CO2 eq.	781852	762145,4	760441	759592	754473	751057	745709	737276	729103	715852	705958	701890	698561	677952	656366
15	Ozone Depletion, emissions	mg R-11 eq.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	Acidification, emissions	g SO2 eq.	4622775	4506492	4496435	4491426	4461220	4441061	4409509	4359745	4311520	4233331	4174951	4150944	4131304	4009696	3882329
17	Volatile Organic Compounds (VOC)	g	11311	11140,74	11126	11119	11075	11045	10999	10926	10856	10741	10655,82	10621	10592	10414	10228
18	Persistent Organic Pollutants (POP)	ng i-Teq	380132	377171,6	376916	376788	376019	375506	374703	373436	372209	370218	368732,3	368121	367621	364526	361284
19	Heavy Metals	mg Ni eq.	425045	417297,3	416627	416294	414281	412938	410836	407520	404307	399098	395208	393609	392300	384198	375712
	PAHs	mg Ni eq.	48479	47588,96	47512	47474	47243	47088	46847	46466	46097	45499	45052,49	44869	44719	43788	42814
20	Particulate Matter (PM, dust)	g	681534	679049,9	678835	678728	678083	677652	676978	675916	674886	673215	671968,5	671456	671036	668439	665718
	Emissions (Water)																
21	Heavy Metals	mg Hg/20	153274	150362,5	150111	149985	149229	148724	147934	146688	145481	143523	142060,9	141460	140968	137923	134734
22	Eutrophication	g PO4	1656	1641,949	1641	1640	1637	1634	1630	1624	1619	1609	1602,363	1599	1597	1583	1567
23	Persistent Organic Pollutants (POP)	ng i-Teq	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	LCC new product	Euro	704123	700423	700103	699944	699693	701308	705104	712161	719266	732378	754521	762685	769260		

Note that there are numerous options when consecutively implemented, which lead to a steady decrease of Total Energy consumption, resulting in 11% savings (but also 9% higher Life Cycle Costs), once all options 1-12 are implemented.

However, this is less than stated elsewhere for metal working machine tools, see e.g.

- claim by SORALUCE[25], that applying the eco-design standard UNE 150.301:2003 yielded a milling machine tools development with an environmental impact reduction of 15% compared to a previous model.
- Savings potential of nearly 50% stated for a mechanical press, see **Table 6-2**, p. 10

The reasons for the above range of figures might be as follows:

- Comparisons made by manufacturers and in research projects typically compare an improved machine tool with a benchmark, where none of the measures has been implemented, and which typically represents a former technology generation. In this study any efficiency gains calculated take into account the issue that most of the measures already have a certain market penetration (our benchmark is the average machine tool brought on the market today)
- Company sources stating high savings potentials ("up to 50%") might have made these claims based on non-realistic use scenarios, which do not reflect the likely production scenario[26].

6.2.2 Base Case 2: Laser cutting machine tool

For laser cutting machine tools, as a rather smaller market segment among CNC machine tools, the LLCC analysis has to remain on a rather superficial level as dedicated data is limited. Two options – which are rather assumptions – are outlined in 6.1.1.2. The resulting graph of consecutively implementing both is depicted in **Figure 6-5**.

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25 http://www.danobatgroup.com/eng/ne/soraluce-the-first-machine-tool-sector-company-to-obtain-ecodesign-certification, accessed February 17, 2012

26 See e.g. statement by Abele et al. in: Abele, E.; Kuhrke, B.; Rothenbücher, S.: Energieeffizienz von Werkzeugmaschinen maximieren, MaschinenMarkt, 22.02.2010

For both options, no changes of investment costs and running costs (besides energy and gas) are considered, although fibre lasers tend to require a higher investment, but less maintenance.

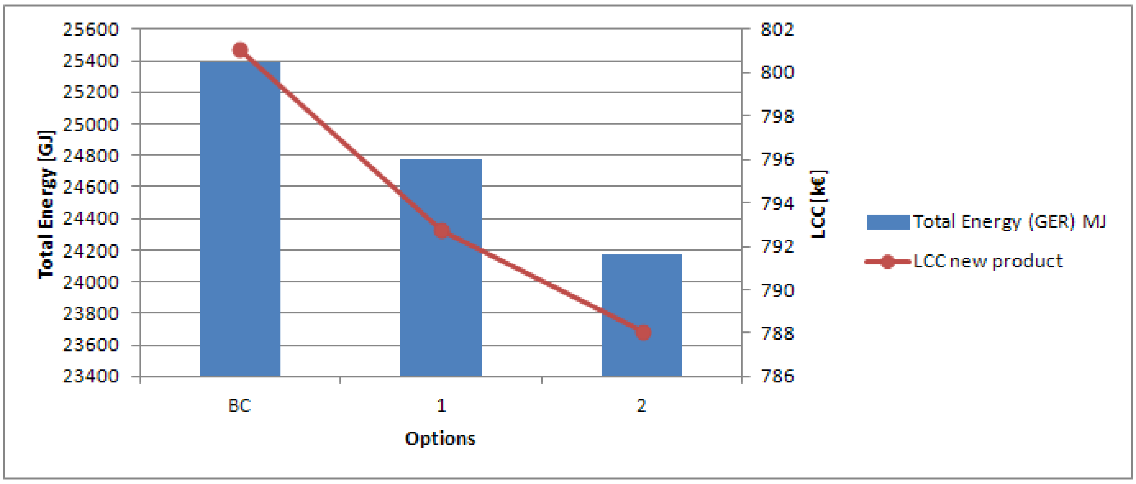

Figure 6-5: Base Case 2 – Total Energy and LCC per Option

Corresponding with the assumptions, Total Energy consumption goes down by 4,8% with implementation of options 1 and 2. LCC (neglecting effects stated above) go down by 1,6%.

Table 6-10: Improvements for Base Case 2 (one product, full life cycle, life cycle costs)

	Other Resources & Waste		BC	1	2
8	Total Energy (GER) MJ	MJ	25389099	24772959	24172223
9	of which, electricity (in primary MJ)	MJ	24810686	24194546	23593810
10	Water (process)	ltr	2003416	1962340	1922291
11	Water (cooling)	ltr	65832860	64189820	62587856
12	Waste, non-haz./ landfill	g	39949001	39234622	38538102
13	Waste, hazardous/ incinerated	g	797117	782919	769077
	Emissions (Air)				
14	Greenhouse Gases in GWP100	kg CO2 eq.	1132108	1105220	1079004
15	Ozone Depletion, emissions	mg R-11 eq.	0	0	0
16	Acidification, emissions	g SO2 eq.	6757147	6598491	6443802
17	Volatile Organic Compounds (VOC)	g	14198	13966	13740
18	Persistent Organic Pollutants (POP)	ng i-Teq	258003	253965	250027
19	Heavy Metals	mg Ni eq.	962102	951531	941225
	PAHs	mg Ni eq.	109536	108321	107138
20	Particulate Matter (PM, dust)	g	627519	624131	620827
	Emissions (Water)				
21	Heavy Metals	mg Hg/20	509232	505259	501386
22	Eutrophication	g PO4	9398	9379	9361

23	Persistent Organic Pollutants (POP)	ng i-Teq	0	0	0
	LCC new product	Euro	801056	792743	788095

6.2.3 Base Case 3: CNC Metal working bending machine tools

Improvement options listed in **Table 6-6**, p. 16, are analysed as follows: The base case assessment from Task 4 is now adjusted by the investment cost changes and energy savings in the use phase, each considering the correction factor. Option 2 includes option 1, option 3 includes option 1 and 2, and so forth. For each consecutive option the cost increase as a share of the initial machinery cost is added (which neglects the fact that a combined implementation might be less costly than only the addition of two measures). Contrary to the costs, the energy savings are not just aggregated, but for each option the point of reference for further savings is the energy consumption level achieved with the option before.

The resulting curve of Life Cycle Costs and Total Energy for Base Case 3 is depicted in **Figure 6-6**. Total Energy is chosen as the key unit indicator. For the other environmental unit indicators see **Table 6-11**, but these run largely in parallel with the indicator Total Energy.

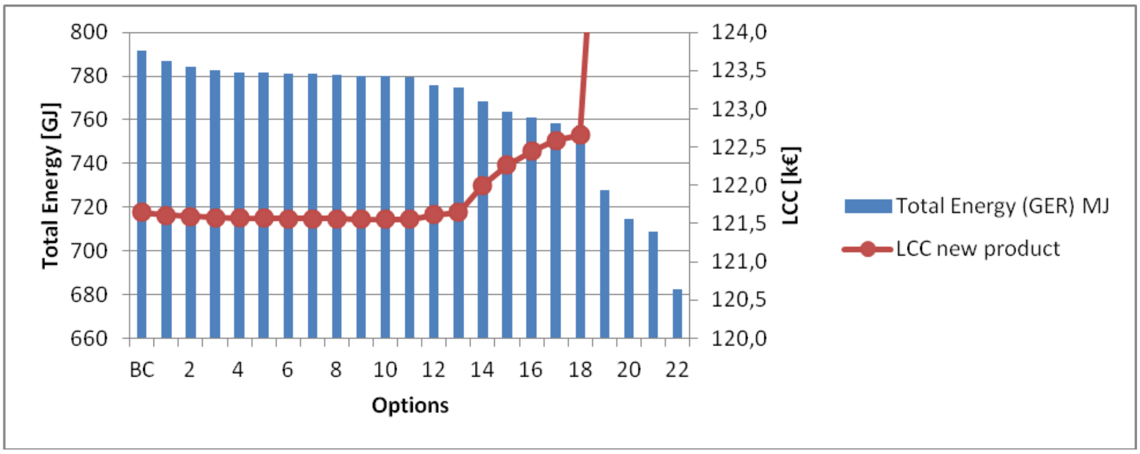

Figure 6-6: Base Case 3 – Total Energy and LCC per Option

The point of Least Life Cycle Costs is option 11 (including consecutive implementation of options 1-10), but Life Cycle Costs changes throughout these options are marginal and reach a cost savings potential of less than 0,1% at option 11, at 1,5% Total Energy savings over lifetime. All other options result in increasing Life Cycle Costs as the energy savings are not compensated by the additional initial investment. The implementation of option 18 features an aggregated result of 0,8% higher Life Cycle Costs at Total

Energy savings of slightly more than 4%. All other options beyond no. 18 result in excessive additional costs (in average), but are nevertheless worthwhile to explore for an individual machine tool, as they feature relevant energy savings potentials.

It should be borne in mind that these figures apply to a highly abstract case. The replies received from manufacturers indicate that for specific machine tools, or specific market segments, there are significant savings potentials available at low or moderate costs, but this has to be assessed carefully on a case-by-case basis, and cannot be stated as a general finding.

Table 6-11: Improvements for Base Case 3 (one product, full life cycle, life cycle costs)

			Option														
	Other Resources & Waste		BC	1	2	3	4	5	6	7	8	9	10	11	12	13	14
8	Total Energy (GER) MJ	MJ	791721	786670	784380	782686	781770	781550	781325	780993	780636	780279	779922	779566	775761	774525	768440
9	of which, electricity (in primary MJ)	MJ	664416	659365	657074	655380	654465	654245	654019	653687	653330	652974	652617	652260	648456	647219	641134
10	Water (process)	ltr	43844	43507	43354	43241	43180	43165	43150	43128	43105	43081	43057	43033	42780	42697	42291
11	Water (cooling)	ltr	1676825	1663355	1657247	1652730	1650289	1649702	1649100	1648215	1647264	1646312	1645361	1644409	1634265	1630967	1614740
12	Waste, non-haz./ landfill	g	7126470	7120614	7117958	7115994	7114933	7114678	7114416	7114031	7113618	7113204	7112790	7112376	7107966	7106532	7099477
13	Waste, hazardous/ incinerated	g	23430	23313	23260	23221	23200	23195	23190	23182	23174	23166	23158	23150	23062	23033	22893
	Emissions (Air)																
14	Greenhouse Gases in GWP100	kg CO2 eq.	40064	39844	39744	39670	39630	39621	39611	39596	39581	39565	39550	39534	39368	39314	39048
15	Ozone Depletion, emissions	mg R-11 eq.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	Acidification, emissions	g SO2 eq.	197102	195801	195211	194775	194540	194483	194425	194339	194248	194156	194064	193972	192992	192674	191107
17	Volatile Organic Compounds (VOC)	g	1577	1575	1574	1573	1573	1573	1573	1573	1573	1572	1572	1572	1571	1570	1568
18	Persistent Organic Pollutants (POP)	ng i-Teq	98776	98743	98728	98716	98710	98709	98708	98705	98703	98701	98698	98696	98671	98663	98623
19	Heavy Metals	mg Ni eq.	34741	34654	34615	34586	34570	34566	34562	34557	34551	34544	34538	34532	34467	34446	34341
	PAHs	mg Ni eq.	4395	4385	4381	4377	4375	4375	4375	4374	4373	4373	4372	4371	4364	4361	4349
20	Particulate Matter (PM, dust)	g	81261	81234	81221	81212	81207	81205	81204	81202	81200	81198	81197	81195	81174	81167	81133
	Emissions (Water)																
21	Heavy Metals	mg Hg/20	19182	19150	19135	19124	19118	19117	19115	19113	19111	19109	19106	19104	19079	19071	19032
22	Eutrophication	g PO4	397	397	397	397	396	396	396	396	396	396	396	396	396	396	396
23	Persistent Organic Pollutants (POP)	ng i-Teq	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	LCC new product	Euro	121645	121607	121590	121577	121570	121569	121567	121564	121562	121559	121556	121554	121615	121646	122000

			Option							
	Other Resources & Waste		15	16	17	18	19	20	21	22
8	Total Energy (GER) MJ	MJ	763904	760924	758543	757452	727813	714604	708795	682429
9	of which, electricity (in primary MJ)	MJ	636599	633618	631238	630146	600507	587299	581489	555124
10	Water (process)	ltr	41989	41790	41632	41559	39583	38702	38315	36557
11	Water (cooling)	ltr	1602646	1594698	1588350	1585440	1506403	1471179	1455687	1385380
12	Waste, non-haz./ landfill	g	7094218	7090762	7088002	7086737	7052373	7037057	7030322	6999753
13	Waste, hazardous/ incinerated	g	22789	22720	22665	22640	21957	21653	21519	20911
	Emissions (Air)									
14	Greenhouse Gases in GWP100	kg CO2 eq.	38850	38720	38617	38569	37275	36699	36446	35295
15	Ozone Depletion, emissions	mg R-11 eq.	0	0	0	0	0	0	0	0
16	Acidification, emissions	g SO2 eq.	189939	189172	188559	188278	180646	177244	175748	168959
17	Volatile Organic Compounds (VOC)	g	1566	1565	1564	1564	1553	1548	1546	1536
18	Persistent Organic Pollutants (POP)	ng i-Teq	98593	98574	98558	98551	98357	98270	98232	98059
19	Heavy Metals	mg Ni eq.	34263	34212	34171	34153	33644	33418	33318	32866
	PAHs	mg Ni eq.	4340	4334	4330	4328	4269	4243	4232	4180
20	Particulate Matter (PM, dust)	g	81108	81092	81079	81073	80910	80837	80805	80660
	Emissions (Water)									
21	Heavy Metals	mg Hg/20	19003	18984	18968	18961	18770	18685	18648	18478
22	Eutrophication	g PO4	396	396	396	396	395	394	394	393
23	Persistent Organic Pollutants (POP)	ng i-Teq	0	0	0	0	0	0	0	0
	LCC new product	Euro	122266	122444	122586	122658	127436	129687	130693	135345

6.2.4 Base Case 4: Non-numerical controlled metal working machine tools

The only identified option for non-NC machine tools is the implementation of IE3 motors (instead of IE2), which is depicted as option 1 in **Figure 6-7**.

IE3 motors represent the point of Least Life Cycle Costs with Total Energy savings of 2,1% and LCC savings of 0,8%. However, these LCC savings are realized over an anticipated lifetime of 18 years, which is far beyond any ROI industry is used to.

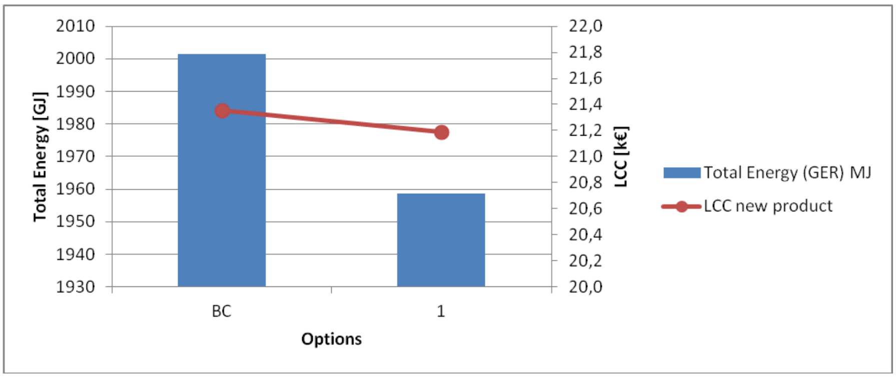

Figure 6-7: Base Case 4 – Total Energy and LCC per Option

What is not displayed with these figures is the fact that, compared to the existing stock of non-NC machine tools, those currently placed on the market are already much more energy efficient, due to the mandatory requirement to implement IE2 motors.

Table 6-12: Improvements for Base Case 4 (one product, full life cycle, life cycle costs)

	Other Resources & Waste		BC	1
8	Total Energy (GER) MJ	MJ	2001356	1958529
9	of which, electricity (in primary MJ)	MJ	1949841	1907013
10	Water (process)	ltr	140188	137333
11	Water (cooling)	ltr	5194965	5080759
12	Waste, non-haz./ landfill	g	3241703	3192047
13	Waste, hazardous/ incinerated	g	45382	44396
	Emissions (Air)			
14	Greenhouse Gases in GWP100	kg CO2 eq.	89136	87267
15	Ozone Depletion, emissions	mg R-11 eq.	0	0
16	Acidification, emissions	g SO2 eq.	514995	503967
17	Volatile Organic Compounds (VOC)	g	1382	1366
18	Persistent Organic Pollutants (POP)	ng i-Teq	22894	22614
19	Heavy Metals	mg Ni eq.	44060	43326
	PAHs	mg Ni eq.	9525	9441

20	Particulate Matter (PM, dust)	g	135054	134819
	Emissions (Water)			
21	Heavy Metals	mg Hg/20	14313	14037
22	Eutrophication	g PO4	113	112
23	Persistent Organic Pollutants (POP)	ng i-Teq	0	0
	LCC new product	Euro	21354	21189

6.2.5 Base Case 5: Wood working machine tools: Table saw

The number of calculated improvement options for light stationary machine tools is limited. Results are depicted in **Figure 6-8**, which shows the implementation of option 1 (cast iron instead of bulk aluminium parts), followed by a consecutive implementation of option 2 (energy efficient motors), i.e. “option 1+2”.

For comparison also the sole effect of option 2 is depicted separately, followed by a consecutive implementation of option 2 (energy efficient motors), i.e. “option 1+2”. With the calculated use scenario the Life Cycle Costs do not decrease at all.

Despite energy savings in use, the additional material consumption for more energy efficient motors over-compensate these savings.

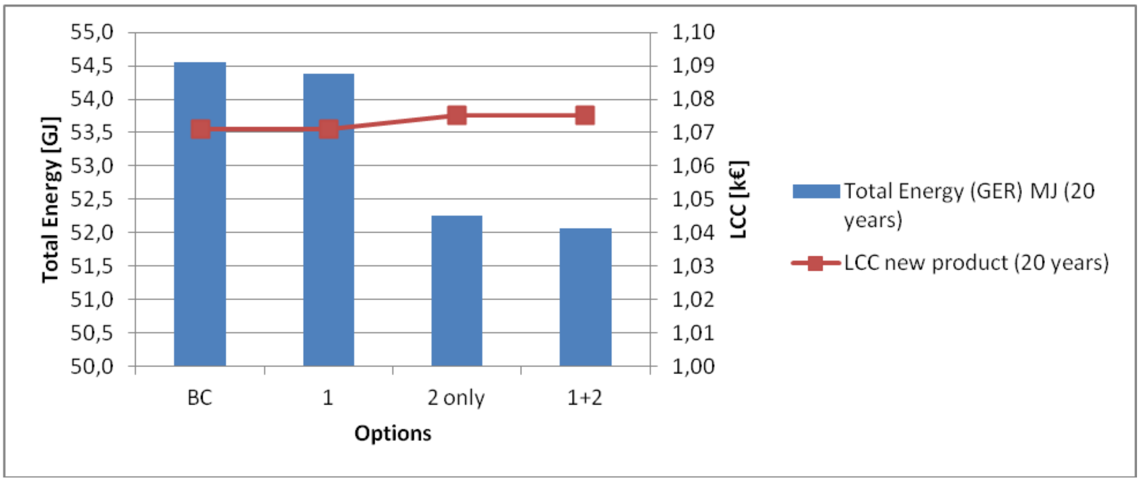

Figure 6-8: Base Case 5 – Total Energy and LCC per Option

These results also correspond with findings made by the US Department of Energy, which stated a minimum payback period of 8,5 years for efficient small motors, partly much more for the higher efficiency benchmarks[27]. The payback period according to our scenario equals roughly 20 years.

Table 6-13: Improvements for Base Case 5 (one product, full life cycle, life cycle costs)

				Option		
	Other Resources & Waste		BC	1	1+2	2
8	Total Energy (GER) MJ	MJ	54556	54107	52068	51799
9	of which, electricity (in primary MJ)	MJ	52619	52596	49996	49971
10	Water (process)	ltr	3528	3539	3387	3364
11	Water (cooling)	ltr	140134	140156	133229	133156
12	Waste, non-haz./ landfill	g	108158	104084	151264	144689
13	Waste, hazardous/ incinerated	g	1751	1751	1692	1692
	Emissions (Air)					
14	Greenhouse Gases in GWP100	kg CO2 eq.	2423	2398	2325	2300
15	Ozone Depletion, emissions	mg R-11 eq.	0	0	0	0
16	Acidification, emissions	g SO2 eq.	14360	14239	14297	14223
17	Volatile Organic Compounds (VOC)	g	32	32	33	31
18	Persistent Organic Pollutants (POP)	ng i-Teq	821	571	673	563
19	Heavy Metals	mg Ni eq.	1108	1119	1250	1199
	PAHs	mg Ni eq.	414	254	261	261
20	Particulate Matter (PM, dust)	g	2162	2251	2570	2253
	Emissions (Water)					
21	Heavy Metals	mg Hg/20	523	472	490	470
22	Eutrophication	g PO4	4	4	5	4
23	Persistent Organic Pollutants (POP)	ng i-Teq	0	0	0	0
	LCC new product	Euro	1071	1071	1075	1075

6.2.6 Base Case 6: Wood working machine tools: Horizontal panel saw

Improvement options listed in **Table 6-8**, p. 22, are analysed as follows: The base case assessment from Task 4 is adjusted now by the investment cost changes and energy savings in the use phase, each considering the correction factor. Option 2 includes option 1, option 3 includes option 1 and 2, and so forth. For each consecutive option the cost increase as a share of the initial machinery cost is added (which neglects the fact, that a combined implementation might be less costly, than only the addition of two measures). Contrary to the costs, the energy savings are not just aggregated, but for

[27] 10 CFR Part 431 - Energy Conservation Program: Energy Conservation Standards for Small Electric Motors, Federal Register / Vol. 75, No. 45 / Tuesday, March 9, 2010, p. 10919; stated for the small business customer subgroup (conditions applicable to the US).

each option the point of reference for further savings is the energy consumption level achieved with the option before. Those options, which are not relevant for this machine tools archetype, are left blank in the graph.

The resulting curve of Life Cycle Costs and Total Energy for Base Case 6 is depicted in **Figure 6-9**. Total Energy is chosen as the key unit indicator. For the other environmental unit indicators see **Table 6-14**, but these run largely in parallel with the indicator Total Energy.

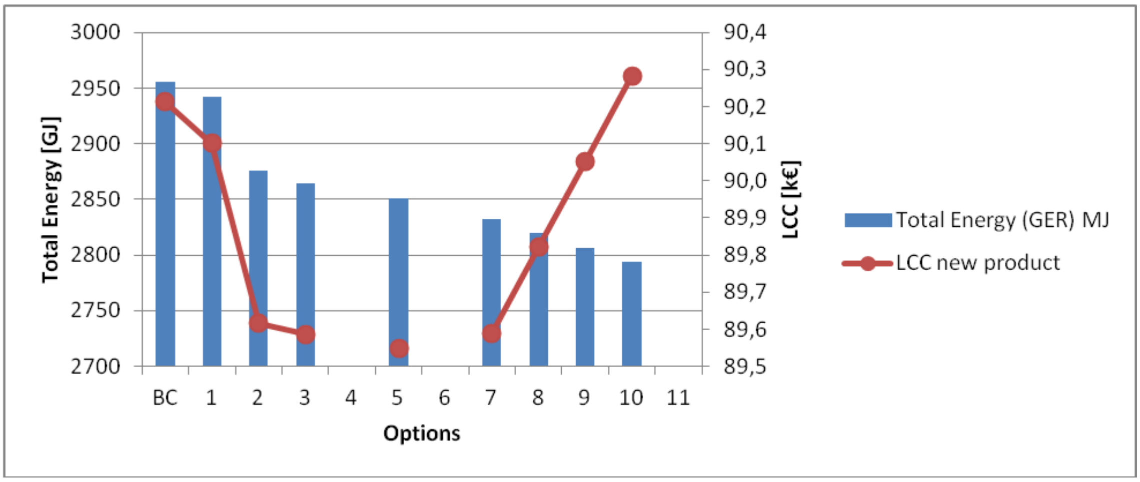

Figure 6-9: Base Case 6 – Total Energy and LCC per Option

Table 6-14: Improvements for Base Case 6 (one product, full life cycle, life cycle costs)

				Option										
	Other Resources & Waste		BC	1	2	3	4	5	6	7	8	9	10	11
8	Total Energy (GER) MJ	MJ	2955871	2942483	2875880	2864127		2851329		2832098	2819359	2806587	2793815	
9	of which, electricity (in primary MJ)	MJ	2780003	2766616	2700013	2688259		2675461		2656230	2643492	2630720	2617948	
10	Water (process)	ltr	189775	188883	184442	183659		182806		181524	180674	179823	178971	
11	Water (cooling)	ltr	7347343	7311643	7134035	7102693		7068564		7017282	6983313	6949254	6915195	
12	Waste, non-haz./ landfill	g	10782517	10766995	10689772	10676145		10661306		10639009	10624240	10609431	10594623	
13	Waste, hazardous/ incinerated	g	149181	148872	147337	147067		146772		146329	146035	145741	145446	
	Emissions (Air)													
14	Greenhouse Gases in GWP100	kg CO2 eq.	135176	134592	131686	131173		130614		129775	129219	128662	128104	
15	Ozone Depletion, emissions	mg R-11 eq.	0	0	0	0		0		0	0	0	0	
16	Acidification, emissions	g SO2 eq.	769243	765796	748645	745619		742323		737371	734091	730802	727514	
17	Volatile Organic Compounds (VOC)	g	2040	2035	2010	2005		2001		1993	1989	1984	1979	
18	Persistent Organic Pollutants (POP)	ng i-Teq	111194	111106	110670	110593		110509		110383	110299	110216	110132	
19	Heavy Metals	mg Ni eq.	75395	75165	74023	73821		73602		73272	73053	72834	72615	
	PAHs	mg Ni eq.	7443	7417	7286	7262		7237		7199	7174	7149	7124	
20	Particulate Matter (PM, dust)	g	106266	106193	105826	105762		105691		105586	105516	105445	105375	
	Emissions (Water)													
21	Heavy Metals	mg Hg/20	32344	32257	31828	31752		31670		31546	31464	31381	31299	
22	Eutrophication	g PO4	1446	1445	1443	1443		1442		1442	1441	1441	1441	
23	Persistent Organic Pollutants (POP)	ng i-Teq	0	0	0	0		0		0	0	0	0	
	LCC new product	Euro	90213	90102	89616	89586		89547		89590	89821	90052	90284	

The point of Least Life Cycle Costs is option 5 (including consecutive implementation of options 1-3), but Life Cycle Costs changes throughout these options are marginal and reach a cost savings potential of 0,7%, at 3,5% Total Energy savings over lifetime. All other options result in increasing Life Cycle Costs as the energy savings are not compensated by the additional initial investment. The implementation of option 9 still represents a reduction (0,2%) of Life Cycle Costs compared to the status quo at Total Energy savings of 5%.

It should be borne in mind that these figures apply to a highly abstract case. For specific machine tools or market segments there might be significant savings potentials at low or moderate costs, but this has to be assessed carefully on a case-by-case basis and cannot be stated as a general finding.

6.2.7 Base Case 7: Wood working machine tools: Throughfeed edge banding machine

Improvement options listed in **Table 6-8**, p. 22, are analysed as follows: The base case assessment from task 4 is adjusted now by the investment cost changes and energy savings in the use phase, each considering the correction factor. For each consecutive option the cost increase as a share of the initial machinery cost is added. Contrary to the costs, the energy savings are not just aggregated, but for each option the point of reference for further savings is the energy consumption level achieved with the option before. Those options, which are not relevant for this machine tools archetype are left blank in the graph.

The resulting curve of Life Cycle Costs and Total Energy for Base Case 7 is depicted in **Figure 6-10**. Total Energy is chosen as the key unit indicator. For the other environmental unit indicators see **Table 6-15**, but these run largely in parallel with the indicator Total Energy.

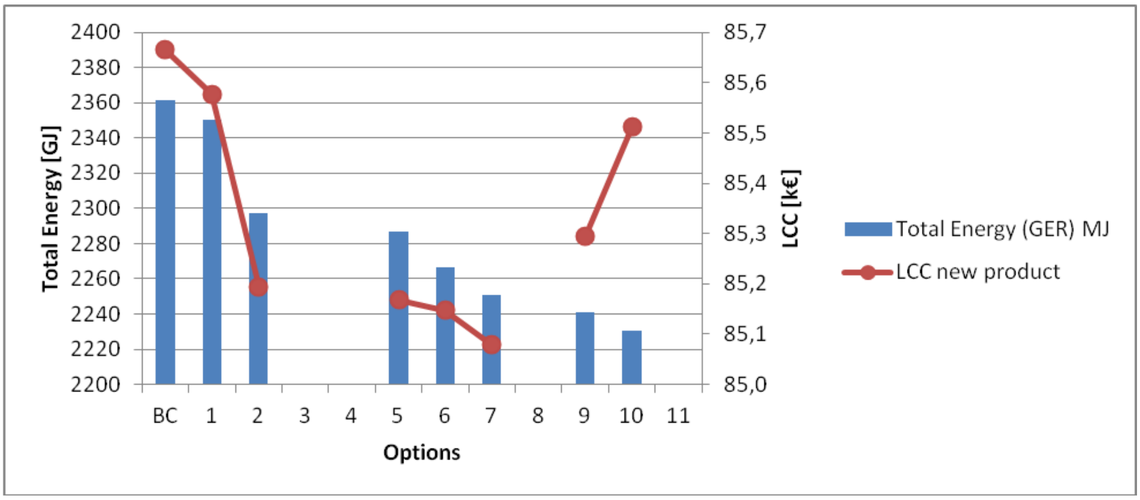

Figure 6-10: Base Case 7 – Total Energy and LCC per Option

The point of Least Life Cycle Costs is option 7 (including consecutive implementation of options 1, 2, 5, and 6), but Life Cycle Costs changes throughout these options are marginal and reach a cost savings potential of 0,7% at 4,7% Total Energy savings over lifetime. All other options result in increasing Life Cycle Costs as the energy savings are not compensated by the additional initial investment. The implementation of option 10 still represents a reduction (0,2%) of Life Cycle Costs compared to the status quo at Total Energy savings of 5,5%.

These results basically confirm the trends identified for the panel saw (Base Case 6), although process and technology is different.

Table 6-15: Improvements for Base Case 7 (one product, full life cycle, life cycle costs)

			Option											
	Other Resources & Waste		BC	1	2	3	4	5	6	7	8	9	10	11
8	Total Energy (GER) MJ	MJ	2361192	2350482	2297200			2286883	2266238	2250867		2240705	2230728	
9	of which, electricity (in primary MJ)	MJ	2214047	2203337	2150055			2139738	2119093	2103722		2093560	2083583	
10	Water (process)	ltr	152300	151586	148034			147346	145970	144945		144268	143603	
11	Water (cooling)	ltr	5849575	5821015	5678929			5651417	5596364	5555374		5528276	5501670	
12	Waste, non-haz./ landfill	g	8255549	8243132	8181354			8169392	8145455	8127633		8115851	8104283	
13	Waste, hazardous/ incinerated	g	70783	70536	69308			69070	68595	68241		68006	67776	
	Emissions (Air)													
14	Greenhouse Gases in GWP100	kg CO2 eq.	107168	106701	104376			103926	103025	102354		101910	101475	
15	Ozone Depletion, emissions	mg R-11 eq.	0	0	0			0	0	0		0	0	
16	Acidification, emissions	g SO2 eq.	630343	627585	613865			611209	605893	601935		599318	596749	
17	Volatile Organic Compounds (VOC)	g	1601	1597	1577			1573	1565	1560		1556	1552	
18	Persistent Organic Pollutants (POP)	ng i-Teq	68471	68401	68052			67984	67849	67748		67682	67616	
19	Heavy Metals	mg Ni eq.	67701	67517	66603			66426	66072	65808		65634	65463	
	PAHs	mg Ni eq.	21205	21184	21079			21059	21018	20988		20968	20948	
20	Particulate Matter (PM, dust)	g	105120	105061	104768			104711	104597	104513		104457	104402	
	Emissions (Water)													
21	Heavy Metals	mg Hg/20	30248	30179	29835			29769	29636	29537		29471	29407	
22	Eutrophication	g PO4	313	313	311			311	310	310		310	309	
23	Persistent Organic Pollutants (POP)	ng i-Teq	0	0	0			0	0	0		0	0	
	LCC new product	Euro	85666	85577	85194			85169	85147	85079		85295	85512	

6.2.8 Base Case 8: Wood working machine tools: CNC machining center

Improvement options listed in **Table 6-8**, p. 22, are analysed as follows: The base case assessment from task 4 is adjusted now by the investment cost changes and energy savings in the use phase, each considering the correction factor. For each consecutive option the cost increase as a share of the initial machinery cost is added. Contrary to the costs, the energy savings are not just aggregated, but for each option the point of reference for further savings is the energy consumption level achieved with the option before. Those options, which are not relevant for this machine tools archetype, are left blank in the graph.

The resulting curve of Life Cycle Costs and Total Energy for Base Case 8 is depicted in **Figure 6-11**. Total Energy is chosen as the key unit indicator. For the other environmental unit indicators see **Table 6-16**, but these run largely in parallel with the indicator Total Energy.

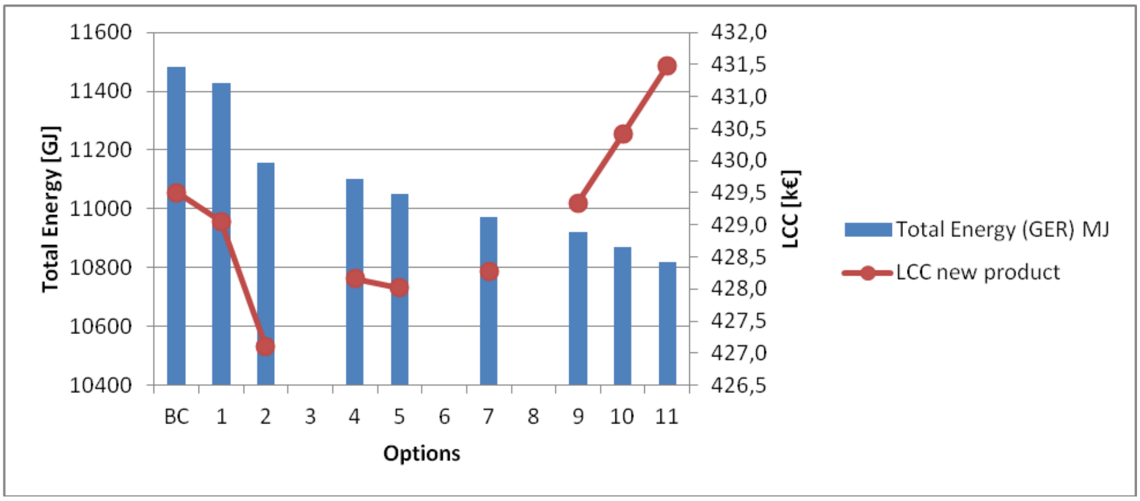

Figure 6-11: Base Case 8 – Total Energy and LCC per Option

Table 6-16: Improvements for Base Case 8 (one product, full life cycle, life cycle costs)

							Option							
	Other Resources & Waste		BC	1	2	3	4	5	6	7	8	9	10	11
8	Total Energy (GER) MJ	MJ	11481681	11427081	11155609		11102790	11049968		10972593		10920586	10868766	10816947
9	of which, electricity (in primary MJ)	MJ	11163960	11109360	10837889		10785069	10732247		10654872		10602865	10551045	10499226
10	Water (process)	ltr	933327	929687	911589		908068	904546		899388		895921	892466	889012
11	Water (cooling)	ltr	29636677	29491077	28767154		28626303	28485443		28279109		28140424	28002239	27864053
12	Waste, non-haz./ landfill	g	20876237	20812931	20498176		20436935	20375690		20285979		20225680	20165598	20105516
13	Waste, hazardous/ incinerated	g	372183	370924	364669		363452	362235		360452		359253	358059	356865
	Emissions (Air)													
14	Greenhouse Gases in GWP100	kg CO2 eq.	515216	512833	500987		498682	496376		493000		490730	488469	486208
15	Ozone Depletion, emissions	mg R-11 eq.	0	0	0		0	0		0		0	0	0
16	Acidification, emissions	g SO2 eq.	3101152	3087092	3017188		3003587	2989985		2970061		2956670	2943326	2929983
17	Volatile Organic Compounds (VOC)	g	5956	5936	5834		5814	5794		5765		5745	5726	5706
18	Persistent Organic Pollutants (POP)	ng i-Teq	131844	131486	129707		129361	129015		128507		128167	127827	127487
19	Heavy Metals	mg Ni eq.	530969	530032	525374		524468	523562		522235		521342	520453	519564
	PAHs	mg Ni eq.	56454	56347	55812		55708	55604		55452		55349	55247	55145
20	Particulate Matter (PM, dust)	g	206138	205837	204344		204054	203763		203338		203052	202767	202482
	Emissions (Water)													
21	Heavy Metals	mg Hg/20	285438	285086	283335		282995	282654		282155		281820	281486	281152
22	Eutrophication	g PO4	5815	5814	5805		5804	5802		5800		5798	5797	5795
23	Persistent Organic Pollutants (POP)	ng i-Teq	0	0	0		0	0		0		0	0	0
	LCC new product	Euro	429507	429054	427098		428159	428021		428278		429346	430415	431485

The point of Least Life Cycle Costs is option 2 (including implementation of option 1). Life Cycle Costs changes throughout these are marginal and reach a cost savings potential of 0,6% at 2,8% Total Energy savings over lifetime. All other options result in increasing Life Cycle Costs as the energy savings are not compensated by the additional initial investment. The implementation of option 9 still represents a reduction (<0,1%) of Life Cycle Costs compared to the status quo at Total Energy savings of nearly 5%.

6.2.9 Base Case 9: Welding equipment

Improvement options mentioned in 6.1.3 are analysed as follows: The base case assessment from task 4 is adjusted now by the investment cost changes and energy and gas savings in the use phase. For each consecutive option the cost increase as a share of the initial machinery cost is added. Contrary to the costs, the energy savings are not just aggregated, but for each option the point of reference for further savings is the energy consumption level achieved with the option before.

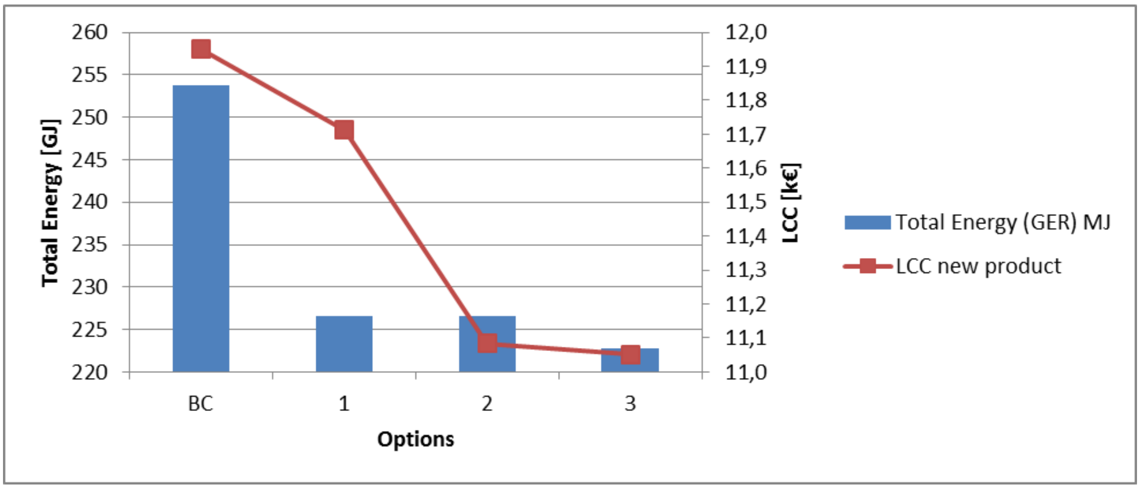

Figure 6-12: Base Case 9 – Total Energy and LCC per Option

The aggregated implementation of options 1-3 turns out to represent the point of LLCC. Realised savings are 12,2% of Total Energy consumption, at 7,5% lower LCC.

Table 6-17: Improvements for Base Case 9 (one product, full life cycle, life cycle costs)

				Option		
	Other Resources & Waste		BC	1	2	3
8	Total Energy (GER) MJ	MJ	253721	226576	226576	222778
9	of which, electricity (in primary MJ)	MJ	233968	206528	206528	202731
10	Water (process)	ltr	16004	14174	14174	13921
11	Water (cooling)	ltr	625535	552362	552362	542235
12	Waste, non-haz./ landfill	g	597337	606125	606125	601722
13	Waste, hazardous/ incinerated	g	22291	21661	21661	21573
	Emissions (Air)					
14	Greenhouse Gases in GWP100	kg CO2 eq.	11465	10282	10282	10117
15	Ozone Depletion, emissions	mg R-11 eq.	0	0	0	0
16	Acidification, emissions	g SO2 eq.	67741	61290	61290	60312
17	Volatile Organic Compounds (VOC)	g	187	177	177	175
18	Persistent Organic Pollutants (POP)	ng i-Teq	4480	4309	4309	4284
19	Heavy Metals	mg Ni eq.	5883	5529	5529	5463
	PAHs	mg Ni eq.	5940	5897	5896	5889
20	Particulate Matter (PM, dust)	g	6072	5936	5936	5915
	Emissions (Water)					
21	Heavy Metals	mg Hg/20	3856	3693	3693	3669
22	Eutrophication	g PO4	36	35	35	35
23	Persistent Organic Pollutants (POP)	ng i-Teq	0	0	0	0
	LCC new product	Euro	11950	11712	11084	11052

6.3 BNAT and long-term systems analysis

In Task 5, a multitude of BNATs with broad technological and sectorial coverage were introduced. It has been highlighted that great efforts are currently invested in research activities concerning resource-efficient and sustainable production plants.

Due to the strong dynamism of the machine tool markets, the quantification of these activities in terms of energy and cost saving potential is a highly difficult task, and depends on numerous factors, many of which may not be foreseeable. This comprises the successful outcome of research activities, with regard to the market maturity and competitiveness derived, in terms of the price of the products, and the applicability of these solutions to different machine tools, and their related machinery. The other factors include the development of novel production technologies, and machines which replace other machineries in the long term, and set standards in energy consumption and efficiency. From this perspective, a long-term observation would necessitate the development of a multitude of different scenarios, of which the probability of occurrence is unfeasible to predict.

At the time of writing, BNATs are developed firstly on a components level, i.e. optimisation of individual components and sub-systems, which does not allow one to later estimate effects at the machinery level (and which itself is highly dependent on how these components are actually implemented within the system). Secondly, research tends to conceptualise the "energy-efficient machine tool", which is a promising approach, but does not allow a credible extrapolation to the whole machine tools market for 2020 or 2025.

6.4 Sensitivity analysis of the main parameters

The intention of the sensitivity analysis is to verify the robustness of the results, particularly the identified environmental impacts and improvement trends, including the identification of the point of Least Life Cycle Costs, if major parameters of the assessment model are analysed. A sensitivity analysis tries to identify which sources of uncertainty might have the most weight, regarding the robustness of the study's conclusions.

In the course of the study the following relevant aspects have been identified:

(1) use pattern assumptions, i.e. shift models, times spent in individual modes

(2) lifetime assumptions

(3) energy costs, which vary widely among countries and company sizes

(4) choice of Base Cases as suitable "abstraction of reality"

(5) stock model and market forecast

Aspects (1) – (3) will be analysed for selected Base Cases and scenarios below on the basis of "per unit machine tool". For these analyses we pick out those Base Cases for which there is the highest likelihood, that such an alternative scenario is applicable.

The choice of the Base Cases as such cannot be verified, as no calculation of alternative archetypal machine tools can be undertaken, due to time constraints – hence this uncertainty remains. As the analysis in Task 6 was undertaken only on a "per unit machine tool" basis, the uncertainty of the stock model and market forecast has to be discussed in Task 7, where total market impacts are quantified.

6.4.1 Shift model

Typical shift models have been chosen for the various Base Cases, but frequently machine tools intended to be covered by a given Base Case are used in a different production environment. For CNC machining centers (and other machine tools represented by BC1) a sensitivity analysis is undertaken with the following parameter changes:

- 1 shift instead of 2 shifts: on-mode 6 hours x 5 days x 50 weeks = 1.500 h/a; standby 2 hours x 5 days x 50 weeks = 500 h/a; off 6760 h/a

With these settings, the results for Base Case 1 change as depicted in **Figure 6-13**: The graph shows both the initial Base Case scenario with improvement options implemented consecutively (i.e., the same as in 6.2.1), and LCC and Total Energy consumption with the adapted shift model. Not surprisingly, Total Energy consumption and Life Cycle Costs, both being closely related to the use phase, decrease. Whereas the point of Least Life Cycle costs in the initial scenario is option 4, this point is now reached already with option 3, but with an even more marginal change compared to the status-quo. The Total Energy savings potential is logically lower as well for the 1-shift-scenario. However, the overall trend is confirmed for the 1-shift-scenario:

- Implementation of several options leads to moderate energy savings
- A couple of options can be implemented for a nearly cost-neutral investment
- Some options with a somewhat higher savings potential are correlated also with higher LCC

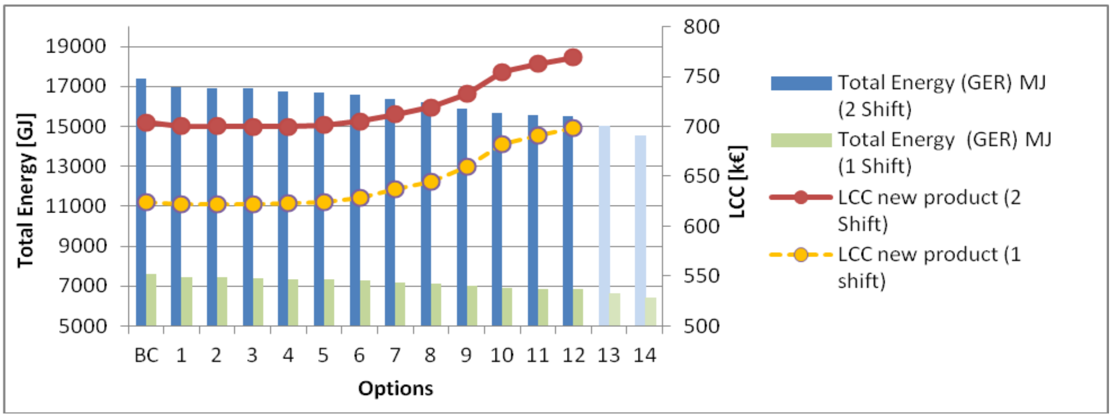

Figure 6-13: Base Case 1 – Sensitivity analysis – shift model change

Wood working is dominated by small businesses / crafts businesses. Consequently, wood working machine tools have been modelled with one shift. In the furniture industry and similar market segments, a two-shift production pattern might be more common. Exemplarily for horizontal panel saws (and other machine tools represented by BC6) a sensitivity analysis is undertaken with the following parameter changes:

- 2 shifts instead of 1 shift: on-mode 1 hour x 6 days x 50 weeks = 300 h/a; idle 15 hours x 6 days x 50 weeks = 4500 h; standby = 3 hours x 6 days x 50 weeks = 900 h, remaining time off-mode

With these settings, the results for Base Case 6 change as depicted in **Figure 6-14**: The graph shows both the initial Base Case scenario with improvement options implemented consecutively (i.e., the same as in 6.2.6), and LCC and Total Energy consumption with the adapted shift model. The Total Energy consumption and Life Cycle Costs, both being closely related to the use phase, increase for the 2-shifts-model compared to the 1-shift-model. Whereas the point of Least Life Cycle costs in the initial scenario is option 5, this point is now reached with option 7, and even with option 10 the LCC is still below the status quo.

This analysis leads to the conclusion that for an industrial 2-shift scenario, the positive effect of implementing consecutively a multitude of options leads to greater relevant savings in terms of Total Energy consumption and moderate cost savings.

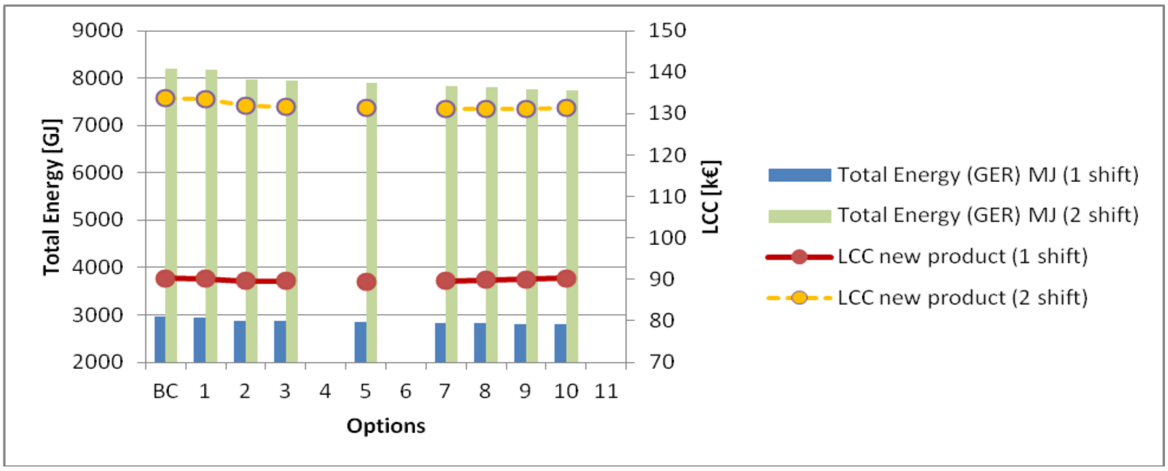

Figure 6-14: Base Case 6 – Sensitivity analysis – shift model change

6.4.2 Electricity price

Once we assume a rather industrial production scenario for wood working machine tools as calculated above, a more appropriate electricity price is that of larger companies. In this sensitivity analysis instead of 0,14 Euro/kWh as the identified proxy for the wood working sector, a lower electricity price of 0,11 Euro/kWh (similar to that for the metal working sector, see Task 2) is anticipated. The aggregated result of changing to a 2-shifts-model and the lower electricity price is depicted in **Figure 6-15**. The point of LLCC remains at option 7, although at roughly 13.350 Euro lower total LCC.

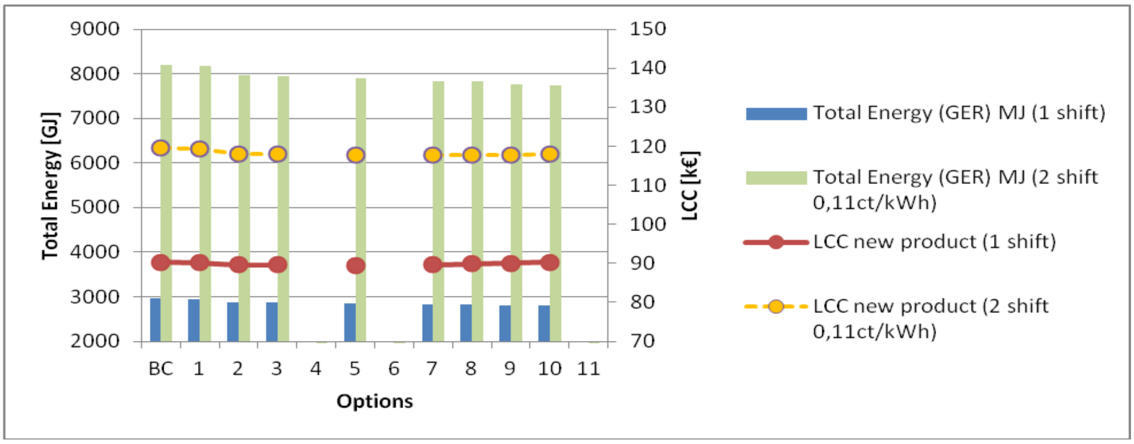

Figure 6-15: Base Case 6 – Sensitivity analysis – shift model change and electricity price change

The changed electricity prices do not have an impact on the overall trends and conclusions.

6.4.3 Lifetime

The lifetime of machine tools is highly uncertain. Despite the survey data and experts' estimations presented in task 2 it must be noted that machinery lifetime is not a constant figure, but subject to economic impacts, introduction of disruptive technologies (and related replacement of conventional ones), and the huge refurbishment and reuse business including exports outside of the EU-27. Furthermore, the expected lifetime differs for different types of machine tools.

For small-stationary wood working tools (BC5) an average lifetime of 20 years has been stated in Task 2, which is likely to hold true for machinery used stationary in workshops, etc. However, machinery used at changing locations, i.e. at construction sites, is much more subject to mechanical stress and wear and tear, and might be used only for 10 years or less. Hence, the scenario for the sensitivity analysis is a lifetime of 10 years, instead of 20 years for the saw in Base Case 5 Table saw. Both cases are depicted in **Figure 6-16Fehler! Verweisquelle konnte nicht gefunden werden.**. As expected, the Total Energy consumption and LCC per unit go down[28], if used only for 10 years, but trends remain the same:

- The additional costs for more efficient motors do not payback over the anticipated lifetime (option 2)
- The incremental reduction of Total Energy consumption could be achieved by material changes (option 1; however, note that one disadvantage is that this would mean a higher weight)

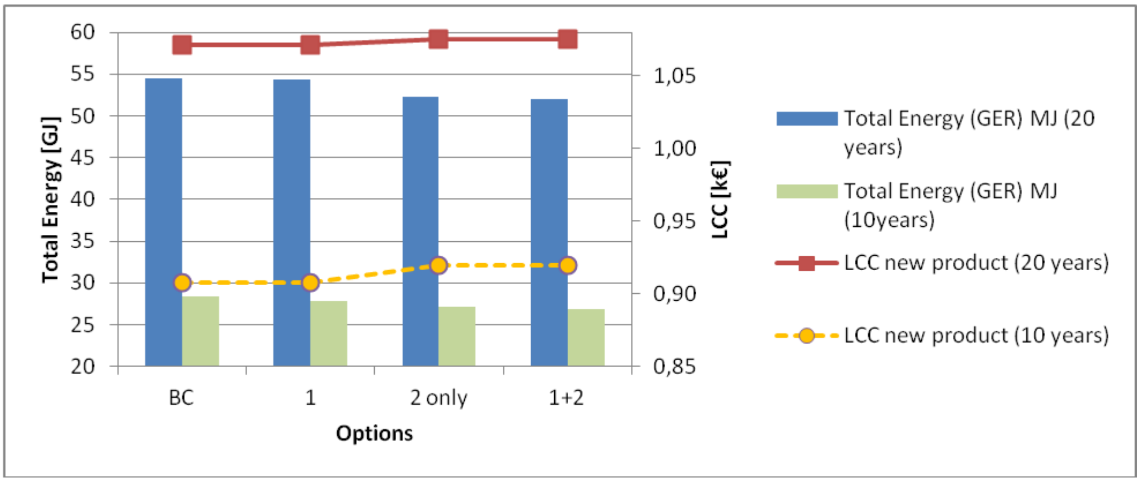

Figure 6-16: Base Case 5 – Sensitivity analysis – shorter lifetime

6.4.4 Use patterns

There is no comprehensive data available on use patterns of machine tools. Although some machine tools manufacturers, via remote maintenance, are aware of the usage of the machines they sell, there is no overview accessible for the machine tools usage at large.

28 But notice, that with half the lifetime actually 2 machine tools will be required where before only one is needed to achieve the same output. This aspect is not taken into account in the above calculation.

As there is an indication that for welding equipment the electricity use is over-estimated[29], Base Case 9 is chosen to calculate an alternative scenario, as follows:

- Drastically reduced use time of 15 minutes per day, i.e. on-mode 62,5 h/a, standby 200 h/a, remaining time disconnected, use of gas reduced accordingly

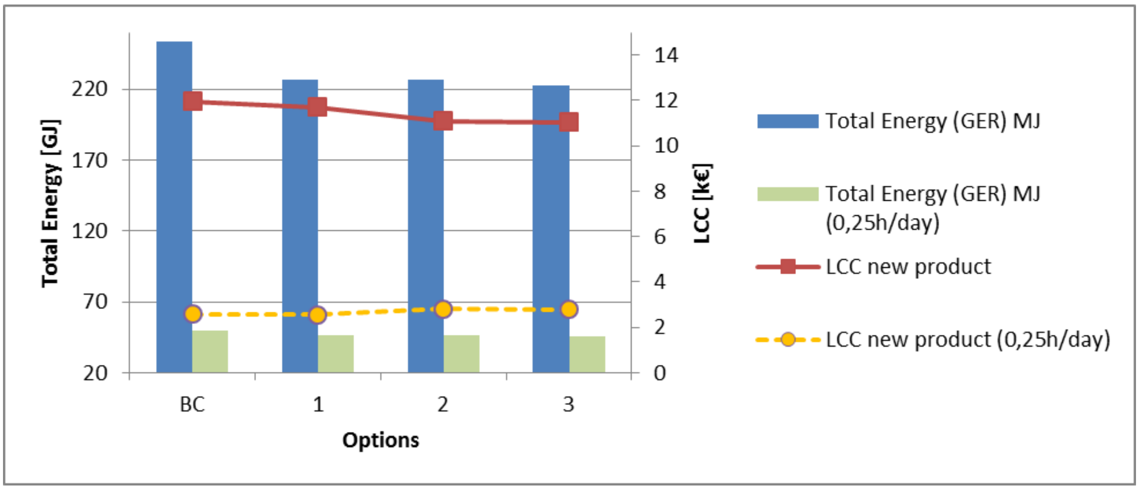

Figure 6-17: Base Case 9 – Sensitivity analysis – use pattern

Both the initial scenario and the reduced use time scenario, are depicted in **Figure 6-17**: Where there was an LCC reduction with the consecutive implementation of improvement options for the baseline scenario, this tendency now is nearly reversed with the alternative scenario. Whereas the increased power source efficiency (option 1) still results in (marginal) LCC savings, all following options result in higher LCC, not a continuous downward trend, which leads to the conclusion that the findings are indeed sensitive to the use pattern assumption in the case of welding equipment.

6.5 Conclusion

The analyses of Least Life Cycle Costs and Best Available Technologies in this task report shows a moderate general savings potential throughout the various Base Cases. The overall results are summarised in **Table 6-18**. The savings potentials at point of Least Life Cycle Costs range from zero to 12,2%. For the arguably most important Base Case 1 group of technologies, representing metal working machine tools, the

[29] In task 4 annual EU-27 electricity costs for welding were calculated at 444 million Euros, whereas US sources (which could not be verified further) state global welding electricity costs of 99 million US-$ only.

savings potential at LLCC is calculated at 4% Total Energy. Similar savings would also be realised with regard to the other environmental indicators.

Most options refer to energy in use, but also material choice and optimising gas consumption for welding have been addressed, and can contribute to environmental savings, although with some limitations.

Table 6-18: Summary improvement potentials per Base Case

	(1) CNC machining centres (and similar)	(2) CNC Laser cutting machine tools	(3) CNC Bending machine tools (and similar)	(4) Non-NC metal working machine tools (and similar)	(5) Table saw (and similar)	(6) Horizontal panel saw (and similar)	(7) Throughfeed edge banding machine (and similar)	(8) CNC machining center (and similar)	(9) Welding equipment
LLCC	-0,6%	- 1,6%	-0,1%	-0,8%	= BC	-0,7%	-0,7%	-0,6%	-7,5%
Total Energy at LLCC	-4,0%	- 4,8%	-1,5%	-2,1%	= BC	-3,5%	-4,7%	-2,8%	-12,2%
Total Energy at LCC break-even	-4,8%	n.a.	-2,2%	n.a.	= BC	-5,0%	-5,5%	-5,0%	n.a.

In general there is no single option with a huge environmental improvement potential. Moderate savings as stated can be realised only with the implementation of several individual options, and what should be called “good machinery design”. As this analysis was meant to address certain archetypal machine tools on a very generic level, it should not be ignored that there might be much larger savings potentials for some machine tools under specific conditions, e.g. for certain applications. This potential can be realised only if the machinery developer has the flexibility to choose from a set of design options those which are most suitable for the target application.