Energy-Using Product Group Analysis - Lot 5

Machine tools and related machinery

Task 1 Report - Definition

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

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Executive Summary – Task 1

As there is a limited common understanding of what is a machine tool and as also standards and legislation do not provide an unambiguous definition of “machine tools” this study has to come up with a “machine tools” definition. This definition, based on engineering considerations that typically cutting, shaping and joining technologies are those employed by machine tools, economic classifications (NACE Rev. 2, and industry statistics), standards on process technologies (such as DIN 8580), and the existing legal framework (machinery directive) is as follows:

A machine tool is a stationary or transportable assembly, which is neither portable by hand nor mobile, and which is dependent on energy input (such as electricity from the grid or stand-alone / back-up power sources, hydraulic or pneumatic power supply, but not solely manually operated) when in operation, and consists of linked parts or components, at least one of which moves, and which are joined together for a specific application, which is the geometric shaping of workpieces made of arbitrary materials using appropriate tools and forming, cutting, physico-chemical processing or joining technologies, the use of which results in a product of defined reproducible geometry, and intended for professional use.

Exemplarily machine tools comprise those for separating / cutting and forming of metals, including those using a laser beam, ultrasonic waves, plasma arc, magnetic pulse, electrolytic etching, etc., for turning, drilling, milling, shaping, planing, boring, grinding etc., for soldering, brazing, or welding. For further examples see the Task 1 report.

Explicitly, machine tools for processing a variety of materials are covered, not only metal working machine tools, i.e. also wood working ones and those for other rigid materials such stones, plastics, glass etc. and welding equipment.

The scope of this study covers also “related machinery” which is *machinery for professional use, which contains components and modules of other machinery, which are similar to those used in machine tools.* For clarification: these components and modules might be used in machines, which do not fall under the definition of machine tools as provided above.

This broader scope is meant to identify potentially a broader environmental improvement potential in industrial production than only with a focus on machine tools as such.

It is intended to follow a modular approach (i.e. machine modules) in the following environmental analysis, taking the machine tools as the starting point, but covering by this modular approach also other ("related") machinery.

A first screening of environmental parameters unveils a **total annual power consumption of machine tools in the range of 200-300 TWh** in the EU-27 largely attributed to metal working machine tools, and a lower share attributed to wood working machinery, welding, brazing and soldering equipment, and stone, glass, and ceramics working machine tools. The screening of machine tools properties against environmental parameters as listed in Annex I of the ErP Directive indicates **highest relevancy of energy consumption in operational and non-operational modes**, and a **moderate relevancy of lubricants' consumption, ease for reuse and recycling, extension of lifetime, waste generation related to the use phase (production waste), emissions to air (saw dust, welding fume...)**.

There are numerous standards existing for machine tools covering safety aspects. In Europe a huge number of these standards are implemented through the machinery directive. With respect to environmental aspects of machine tools there are only very few relevant standards yet such as ISO 5170 on lubrication systems and ISO 11204 on noise test methods. The first standard tackling specifically machine tools with regard to environmental aspect is the planned ISO/NP 14955 - Environmental evaluation of machine tools. Taking the current status of approved and published standards as a basis, there are **gaps in standardisation** of machine tools specifically regarding the **eco-design process, marking / labelling of materials / components (e.g. identification of hazardous substances), power consumption measurements (machines and modules), power modes, power management, consumption of lubricants (measurements, assessment), consumption of compressed air (measurements), process waste generation measurement including yield losses**.

Most relevant legislation on the European level regarding EHS issues are:

- Directive 2006/42/EC on machinery
- Directive 2002/96/EC on waste electrical and electronic equipment (WEEE)
- Directive 2002/95/EC on the restriction of the use of certain hazardous substances in electrical and electronic equipment (RoHS)
- Commission Regulation (EC) No 640/2009 on ecodesign requirements for electric motors

Within the industry there is no voluntary agreement yet, but CECIMO initiated a Self-Regulation Initiative (SRI) in 2009, so far addressing metal working machine tools only.

1 TASK 1 – DEFINITION

1.1 Subtask 1.1 – product classification and definition

- **Subject of examination**

The primary subject of this preparatory study is defined as 'machine tools'. The product scope remains being the **only reference framework** for the whole study when discussing economic figures, base cases, improvement options, and the like.

As there are similarities between machine tools and other kinds of machinery and equipment, in a subsequent approach, the scope of this study will cover **equipment related to machine tools** and **modules** of other machinery, which are similar to those used in machine tools. Machineries which contain similar modules will be **not** subject to forthcoming analysis (market data, base cases, etc.) but will be indirectly affected by findings deriving from the machine tool examination (e.g. improvement options for certain modules).

- **Objective of task 1.1**

The main objective of this first task is to set a sound foundation for appropriate study results by **defining and classifying the product scope** for ENTR Lot 5 "machine tools and related machinery". The definition will be based on existing definitions and adaptations of these in order to serve the aim of the study.

In order to select a proper product scope from the existing options (e.g. definitions and scopes deriving from market statistics, technical standards, and labelling schemes[1]) it is necessary to reflect or match the boundaries of this product scope with the task requirements of the whole study. This means that the product scope needs to fit:

- Test standards reflecting environmental issues such a power consumption measurement procedures (task 1)
- Product and technology trends (task 2 and 6)
- Available market data and respective typical market segmentation (task 2 and 4)

1 Compare suggestions from the tender specifications, EUROPEAN COMMISSION, *ENTR/2009/035*, 2009, p.24.

- Use environments and respective typical use patterns (task 3 and 4)
- Products design characteristics and respective technical parameters (task 4)
- Relevant environmental impacts and expected improvements (task 5)

Against this background the first subtask “product definition” is most critical because it determines to great extent the boundaries of following tasks and the overall result of the study – providing options for ecodesign requirements.

- **Structure and design of task 1.1**

Based on various definitions and classifications of machine tools, as traceable in (specialist) literature, guidelines, directives, studies, and the like the scope regarding machine tools will be defined and also be specified for metal working, woodworking, and welding / soldering / brazing in particular.

Subsequently, the product scope will also be classified in terms of PRODCOM categories, whereby the previous subdivision is taken up, meaning that metal working, woodworking, welding / soldering / brazing, and other machine tools will be examined separately.

Taking into account technological convergences of machine tools with other manufacturing machines, the scope will be extended to those which contain similar modules, which in the following will be addressed as ‘related machinery’.

1.1.1 Existing definitions and product classifications

1.1.1.1 DIN 8580

From the perspective of the manufacturing processes DIN 8580[2] provides a broadly accepted classification and terminology for all kinds of processes, Figure1-1. Concerning the aim of our study, the standard provides no further evidence about the allocation of manufacturing process to the correspondent machine, especially machine tools. In fact, DIN 8580 provides an indication concerning conventionally used technologies in the field of manufacturing.

2 DEUTSCHES INSTITUT FÜR NORMUNG, *DIN 8580:2003-09 Fertigungsverfahren – Begriffe, Einteilung*, 2003.

Figure1-1: General Scope – Overview Manufacturing Processes classified according to DIN 8580 (selection)

1.1.1.2 Level of automation of machine tools

Machine tools can be distinguished according to the level of automation, as described in Figure 1-2 (depicted is a scheme reflecting cutting machine tools). A “machine” is characterised by the presence of cutting and feed drives, whereby the sequence of motions as well as tool and workpiece change is carried out by manpower. For the “NC-machine”, a numerical control is incorporated to automatically run the machining of the workpiece. An entire processing of an individual workpiece can be performed in a “centre”, for which several tools can be deployed and changed automatically. Standalone series production for similar workpieces can be applied for a “cell”, in which the complete process of machining is performed automatically, enabled by the extension of automated workpiece change. The highest level is reached in a “system”, where the entire manufacturing process is automated and generally consists of several production machineries, workpiece and tool flow systems as well as supply and waste disposal logistics, controlled by a master computer. [3]

In regard to the ecological performance, it is likely that the increase of automation goes along with rising environmental significance, in particular energy use, considering that manpower is successively replaced by electric current. Automated machine tools are designed for continuous working, which leads to a greater extent of energy consumption during the use phase compared to low tech machine tools. At the same time, raising consumption of electricity causes an increase in heat development, which requires additional cooling. Thus, the degree of automation serves as an ecological indicator, e.g. in regard to the energy demand or manner of use (series production, occasional use, and the like). However, coming along with automation, the productivity of a machine is significantly improved, which should be considered as well. These deliberations are taken into consideration in Figure 1-2.

[3] HIRSCH, A., *Werkzeugmaschinen: Grundlagen: Lehr- und Übungsbuch*, 2000, p. 4.

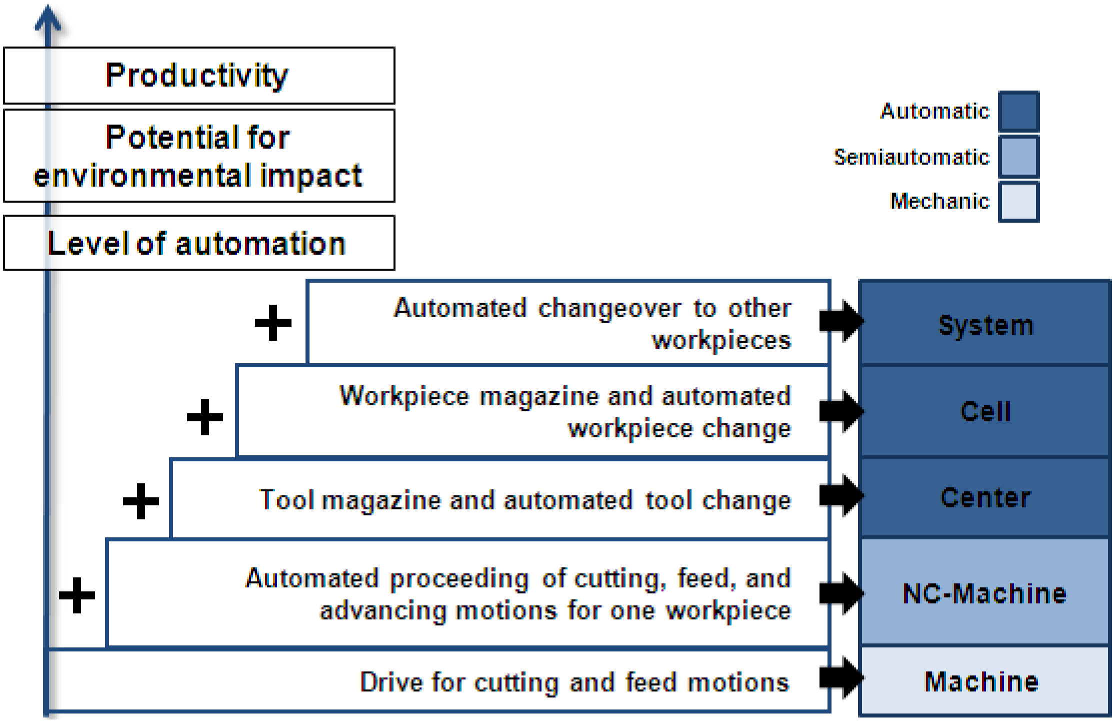

Figure 1-2: Distinction of machine tools according to level of automation.

1.1.1.3 DIN 69651

The drawn back standard DIN 69651[4] deals with the classification of metal working machines and defines machine tools as "mechanised and more or less automated production facilities, which enable the determined shape or transformation of the workpiece through relative motion between tool and workpiece",[5] thus covering a broad range of working machines. The classification has been performed according to numerous considerations as illustrated in Figure1-3. It is worth to point out that general manufacturing processes for metal working according to this standard are primary shaping, forming, separating, joining, coating, and changing material properties, as

[4] DEUTSCHES INSTITUT FÜR NORMUNG, *DIN 69651 – Werkzeugmaschinen für die Metallverarbeitung*, 1981.

[5] Translation by Fraunhofer, original version in German reads as follows: "*Werkzeugmaschinen sind mechanisierte und mehr oder weniger automatisierte Fertigungseinrichtungen, die durch relative Bewegungen zwischen Werkzeug und Werkstück eine vorgegebene Form oder Veränderung am Werkstück erzeugen.*", DEUTSCHES INSTITUT FÜR NORMUNG, ref 4, part 1, p. 3.

demonstrated in Figure1-4. The following figures shall illustrate the classification according to this outline:

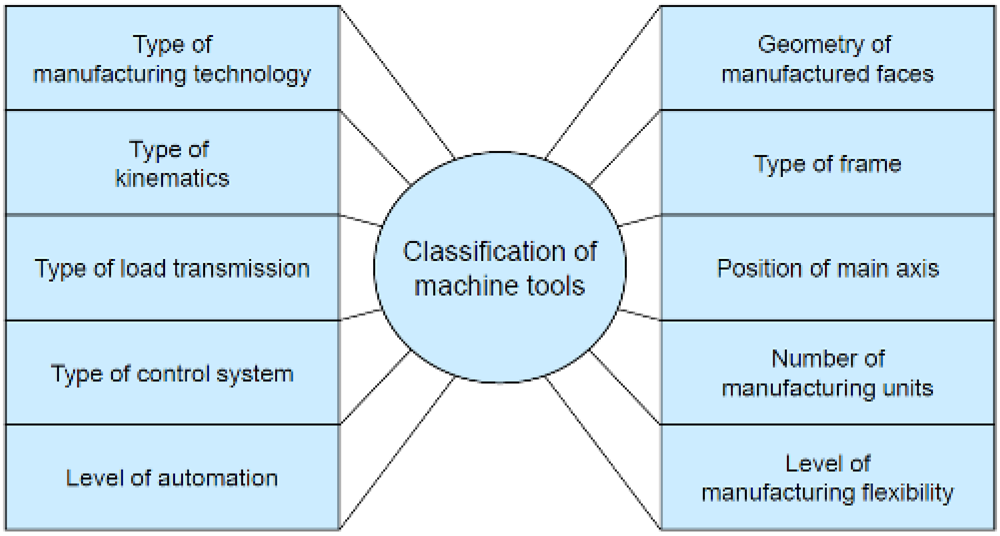

Figure1-3: Classification of machine tools according to DIN 69651

Figure1-4 implies that DIN 69651 can be perceived as an enhancement of DIN 8580 (as described in 1.1.1.1) due to the allocation of technologies and processes to the appropriate machines.

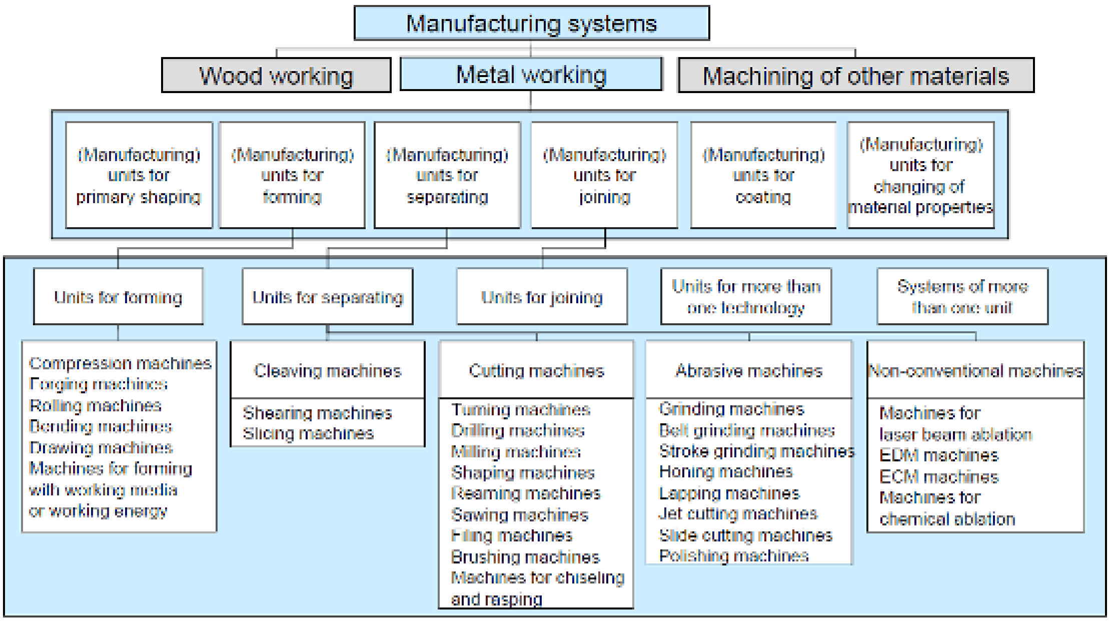

Figure1-4: Machine Tools and manufacturing processes according to DIN 69651

1.1.1.4 Directive 2006/42/EC on Machinery

The revised Machinery Directive 2006/42/EC[6] replaced the former directive 98/37/EC in order to consolidate "the achievements of the Machinery Directive in terms of free circulation and safety of machinery while improving its application".[7] In accordance with Directive 2006/42/EC, the word 'machinery' describes "an assembly, fitted with or intended to be fitted with a drive system other than directly applied human or animal effort, consisting of linked parts or components, at least one of which moves, and which are joined together for a specific application […]". The directive basically deals with safety aspects and the agreement on uniform European standards to avoid extra costs and to prevent from unsafe products in the market. Therefore, it is intended to cover the whole range of all types of machines. Although implicitly addressing machine tools being in the scope of this directive,[8] no further specifications which could indicate a machine tool classification are being made.[9]

1.1.1.5 DIN EN ISO 23125:2010

The draft for DIN EN ISO 23125[10] is a specification of the Machinery Directive concerning safety matters on turning machines. Implementing measures require the classification of machine with certain features into groups, thus turning machines where divided into four groups, according to the following pattern:

Table 1-1: Product classification according to DIN EN ISO 23125:2010

Group No.	Group name	Subdivision in sizes
Group 1	Manually controlled turning machines **without** numerical control	Small and Large
Group 2	Manually controlled turning machines **with limited** numerically controlled capability	Small and Large

[6] EUROPEAN COMMISSION, *Directive 2006/42/EC on Machinery*, 2006.

[7] EUROPEAN COMMISSION - ENTERPRISE AND INDUSTRY - MECHANICAL ENGINEERING, 2010.

[8] Including machine tools accomplished by the exclusion principle, compare ref 6, Article 1, No.2; note: additionally, Machine Tools are excluded from the Low Voltage Directive 2006/95/EC

[9] Regarding the aim and the scope, however, this directive does not cope with classification issues at all.

[10] NORMENAUSSCHUSS WERKZEUGMASCHINEN (NWM) IM DIN, *DIN EN ISO 23125:2010*, 2010.

Group No.	Group name	Subdivision in sizes
Group 3	Numerically controlled turning machines and turning centres	Small and Large
Group 4	Single- or multi-spindle automatic turning machines	No subdivision

Concerning the size of the turning machine, further distinctions are made:

Table 1-2: Product distinction small and large turning machines according to DIN EN ISO 23125:2010

Criterion	Small turning machines	Large turning machines
Horizontal spindle turning machines and turning centres		
Distance between centres (BC) [mm]	≤ 2000	> 2000
Designed to accept workpiece clamping devices [mm, Outside diameter]	≤ 500	> 500
Vertical turning machines, inverted spindle turning machines including pick-up machines and turning centres		
Designed to accept workpiece clamping devices [mm, Outside diameter]	≤ 500	> 500

1.1.1.6 Nomenclature générale des activités économiques (NACE) Rev. 2

Up to this point of the study, regarding the existing classification introduced thus far, it is apparent that the definitions stated above either do not directly address machine tools as such (e.g. DIN 8580, Machinery Directive) or their field of classifying is restraint to a very specific sub market of machine tools (e.g. DIN EN ISO 23125).

In order to provide a qualitative approach how to categorize and classifying machine tools, the NACE classification can serve as a basis. NACE is the “statistical classification of economic activities in the European Community”[11] in order to create statistical standards for the EU-wide economy. Products which could be considered as machine tools are aggregated in group 28.4 “Manufacture of metal forming machinery and machine tools”, furthermore divided into both classes 28.41 “Manufacture of metal forming machinery“ and 28.49 “Manufacture of other machine tools“. Although a distinction has been made between machine tools for working metal and those for working other materials, a broad range of all varieties of industrial production machineries are covered by the term ‘machine tools’, as summarized in Table 1-3.

11 EUROSTAT, *Methodologies and Workingpapers - NACE Rev. 2 - Statistical classification of economic activites in the European Community*, 2008, p. 7.

Table 1-3: NACE Rev. 2 classification on metal forming machinery and machine tools

28.4 Manufacture of metal forming machinery and machine tools
28.41 Manufacture of metal forming machinery
This class includes: - manufacture of machine tools for working metals, including those using a laser beam, ultrasonic waves, plasma arc, magnetic pulse etc. - manufacture of machine tools for turning, drilling, milling, shaping, planning, boring, grinding etc. - manufacture of stamping or pressing machine tools - manufacture of punch presses, hydraulic presses, hydraulic brakes, drop hammers, forging machines etc. - manufacture of draw-benches, thread rollers or machines for working wires This class excludes: - manufacture of interchangeable tools, see 25.73 - manufacture of electrical welding and soldering machines, see 27.90
28.49 Manufacture of other machine tools
This class includes: - manufacture of machine tools for working wood, bone, stone, hard rubber, hard plastics, cold glass etc., including those using a laser beam, ultrasonic waves, plasma arc, magnetic pulse etc. - manufacture of work holders for machine tools - manufacture of dividing heads and other special attachments for machine tools - manufacture of stationary machines for nailing, stapling, gluing or otherwise assembling wood, cork, bone, hard rubber or plastics etc. - manufacture of stationary rotary or rotary percussion drills, filing machines, riveters, sheet metal cutters etc. - manufacture of presses for the manufacture of particle board and the like - manufacture of electroplating machinery This class also includes: - manufacture of parts and accessories for the machine tools listed This class excludes: - manufacture of interchangeable tools for machine tools (drills, punches, dies, taps, milling cutters, turning tools, saw blades, cutting knives etc.), see 25.73 - manufacture of electric hand held soldering irons and soldering guns, see 27.90 - manufacture of power-driven hand tools, see 28.24 - manufacture of machinery used in metal mills or foundries, see 28.91 - manufacture of machinery for mining and quarrying, see 28.92

1.1.1.7 Production Communautaire (PRODCOM)

Based on the NACE Rev. 2 structure as mentioned above, the PRODCOM database contains manufacturing data for section B (mining and quarrying) and C (manufacturing), divided into a range of groups from 7.1 to 33.0.[12]

12 Furthermore, categories 399900Z0, 399900Z1, 399900Z3 are included, but will be of less importance for the study.

As mentioned above, regarding the quantity of data material, this database is a unique source when it comes to an economic assessment. Hence, the overall product scope should be complementary and referable to the categories predefined in the PRODCOM database.

As for this study, the decision was made working with PRODCOM and the nomenclature according to NACE Rev. 2. The PRODCOM classes 28.41 and 28.49 will provide the foundation for the study, as they are already predefined as machine tool devices.

1.1.1.8 Study for preparing the 1st Working Plan of the Ecodesign Directive

The EPTA Study[13] based on Article 16 of the Ecodesign Directive 2005/32/EC respectively 2009/125/EC was contracted with the purpose of identifying, which product groups should be listed in the European Commission's EuP Working Plan, and thus potentially subject to an implementation of measures. The methodology that is being used in this study can be described as follows:

- Identification of all Energy Using Products within the scope of the EuP Directive
- Classification of all potential EuPs in product categories[14]
- Identification of priority EuPs and final ranking of the product categories into Priority A EuPs and Priority B EuPs[15]

Due to their findings, they identify machine tools as a relevant class eligible to be examined for improvement potential.[16] A qualitative indication which products ought to be considered as machine tools is listed below:

13 EPTA LTD, *Study for preparing the first Working Plan of the EcoDesign*, 2007.

14 Note: EPTA is using a different nomenclature then PRODCOM to describe similar things (a "category" according to EPTA most likely corresponds with a "group" in PRODCOM).

15 EPTA LTD, ref 13, p. 4.

16 This conclusion derives from an assessment by the means of MEEuP (Methodology study for Ecodesign of Energy-using Products, carried out by VHK in 2005), which will be subject later in this study.

Table 1-4: Machine Tool features and products according to the EPTA Study[17]

Machine Tool features	Products	
Made for Manufacturing & Industrial Use	Lathes - Horizontal lathes - Vertical lathes	Machines for - Milling - Grinding - Bending - Straightening - Folding - Flattening - Cutting - Drilling

The Working Plan Study by EPTA explicitly made a distinction between "machine tools" and equipment for joining processes of metals ("Automatic and Welding Machines"), although from an engineering point, machines for joining processes can be considered "machine tools" too (see DIN 69651 above). Just as machine tools, the product category "automatic and welding machines" is one of the 25 product categories with highest priority ("A") for inclusion in the Work Plan. Thus, considering the technical convergence of both product groups, automatic and welding machines will be covered by the scope of this study.[18]

1.1.1.9 Technical classification of woodworking machines and auxiliary machines for woodworking

The International standard ISO 7984:1988 ISO 7984:1988 „Woodworking machines – Technical classification of woodworking machines and auxiliary machines for woodworking" provides an approach for the classification of woodworking machinery from a technological perspective and to some extent in regard to the texture of the end product, additionally considering machines which perform multi-purpose processes. The aim of this standard is to harmonize the designations of different types of woodworking machines in order to overcome language barriers and reduce obstacles to trade. The general definition of woodworking machines provided by ISO 7984 reads as follows:

Woodworking machines, for the purposes of this classification, are stationary or portable machines intended for processing wood, material derived from wood, cork, bone,

[17] EPTA LTD, ref 13, p. 251.

[18] Note: The European Commission evaluated these 25 product categories further to establish a list of 10 product categories in the Work Plan. Whereas machine tools are explicitly listed in the Work Plan, automatic and welding machines are not.

ebonite, plastics and other similar materials (also including assembling, coating machines).

As an outstanding restriction, the definition covers all sorts of machines which are capable to process wood and similar materials. Considering that both stationary and portable machines are addressed, the multitude of small scale handheld woodworking machines is comprised. Compliant with the technological perspective, machines for processing materials having similar properties to wood are covered, so that plastics are included as well. However, the product classification of ISO 7984 goes beyond the definition (e.g. 51.1 Lifting equipment (mobile lifting tables, tilting hoists, etc.), or auxiliary machines such as those for saw blade maintenance (sharpening machines, filling machines, etc.)), which is detailed in Table 1-5.

Table 1-5: Classification of woodworking machines according to ISO 7984:1988

Type of woodworking machine	Specification/Definition
Cutting machines	**Chipless cutting machines**: Cutting machines change the shape or the dimension of a workpiece without the removal of chips
	Cutting machines with the removal of chips or particles: Cutting machines change the shape or the dimension of a workpiece with the removal of chips
Deforming machines	Mechanically change the form and/or physical characteristics of the workpiece by action on its structure
Joining and assembling machines, including coating.	Are for joining two or more pieces, coating machines are for joining a piece ton a coating material (glue, lacquer, etc.)
Equipment for Wood conditioning (seasoning, preserving, etc.).	Modifies the characteristics of the wood by extraction, impregnation or other processes
Auxiliary machines and equipment for the woodworking industry.	Are not strictly woodworking machines but are specifically used by the woodworking industry
Portable machines (hand-held machines) and machining heads	**Portable machines**: Portable machines are power-driven machines, hand-held whilst operating. They include flexible drive and other hand-held machines, e.g. floor sanders, deck planers, etc.
	Machining heads: Machining heads (unit heads) are self-contained production units. They are designed to be mounted on and to supplement existing machines, or, when mounted on a separate base, to form an independent machine.
Multi-purpose machines using various working methods covered by group 1 to 6.	Multi-purpose machines using various working methods covered by groups 1 to 6; in these machines, the workpiece, after initial entry, is fully processed without further manual assistance.
Other machines	Special machines or sets of special machines are designed for the sole purpose of manufacturing particular end products.

1.1.1.10 VDW classification of machine tools ('Red Book')

The "Red Book"[19] issued by the German machine tool Builders' Association (Verein Deutscher Werkzeugmaschinenfabriken (VDW), in the following VDW) provides a precise and detailed overview of distinctive types of machine tools by German manufacturers, along with specific technical details. The index of machine tool types, according to which pattern the classification is being preceded, is subject to Annex I – VDW classification on Machine Tools (Table 3-1, p. 141). The 'Red Book' covers the broad range of machinery for primarily processing metal,[20] whereas machines for processing other materials are not involved, thus not being regarded as a machine tool. The classification also covers periphery systems, e.g. "Control Systems and Software" and "Industrial Plants for Metal Working". Welding and soldering machines, however, are not considered as machine tools.

1.1.1.11 Qualitative definitions for machine tools

In order to set up an approach in engineering terms, the following definition by Kienzle on machine tools gives a basic idea how to border the product scope:[21]

"*Machine tools are machines for the fixed mechanical movement between tools and workpieces. In this regard, tools are processing the workpieces in determined shapes.*"

In general, the perception of Kienzle is that changing the shape of a random component in a definite way is the outstanding feature of a machine tool.

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[19] VEREIN DEUTSCHER WERKZEUGMASCHINENFABRIKEN e. V. (VDW), VERBAND DEUTSCHER MASCHINEN- UND ANLAGENBAU e. V. (VDMA), *Machine Tools and Manufacturing Systems from Germany*, 2009. Additional information provided on http://www.vdw.de/web-bin/owa/homepage?p_bereich=leistungsangebot&p_menue_id=1000000022&p_zusatzdaten=dok_zeige_ordner&p_zusatz_id=601&p_sprache=e

[20] Note: the Red Book also comprises few very precise niches, such as machines for the precision cutting of diamonds.

[21] Translation by Fraunhofer, original version in German reads as follows: "*Werkzeugmaschinen sind Maschinen zur zwangläufigen mechanischen Bewegung von Werkzeugen und Arbeitsstücken. Die Werkzeuge bearbeiten dabei die Arbeitsstücke in bestimmten Formen.*"; KOCH, R., KIENZLE, O., *Handwörterbuch der gesamten Technik und ihrer Hilfswissenschaften Vol. 2*, 1935, p. 731.

By generally defining machine tools as a machine, the definition is compatible with the Machinery Directive as explained in 1.1.1.4. Hence, machine tools can be considered as a particular construction type of a machine in the sense of the Directive.

The use of the term “determined shapes” implicitly imposes several specific requirements onto the workpiece. The word “determined” refers to a fixed, definite, and therefore reproductive way of processing. By comprising the “shapes” into the expression, we conclude that the actual existence of a workpiece’s shape is of crucial significance. In order to provide this feature, the shape has to be existent before, during and after working procedure. To recap our findings: “determined shapes” refer to a reproductive working procedure, in which a particular shape of a workpiece has to be existent before, during, and after the process.

The understanding of workpieces with determined (thus geometric) shapes becomes clearer when comprising the recent definitions on machine tools. An attempt to qualitatively describe machine tools has been phrased by Milberg in the frame of DIN 8580 (see 1.1.1.1). He classifies forming and cutting being the two common applied technologies for machine tools.[22] According to his explanation, machine tools are “working machines for working primarily metallic material with predetermined geometry and appropriate tools”,[23] hence arguing in the sense of the Kienzle definition as stated above.

Comprising a current definition deriving from the DUBBEL, the international acknowledged reference book for mechanical engineering, the significance of geometrical determination of the workpiece is emphasized:

“Due to the relative movement between tool and workpiece and procedural power transmission (separative, transformative), a workpiece of determined elementary shape will be transformed into a predestined shape.”[24]

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[22] MILBERG, J., *Werkzeugmaschinen Grundlagen - Zerspantechnik, Dynamik, Baugruppen und Steuerungen*, 1995, p. 2.

[23] Translation by Fraunhofer, original version in German reads as follows:“*[Dies sind] Arbeitsmaschinen zum Bearbeiten überwiegend metallischer Werkstoffe nach vorher bestimmter Geometrie unter Verwendung geeigneter Werkzeuge*.“

[24] Translation by Fraunhofer, original version in German reads as follows: ”*Durch Relativbewegungen zwischen Werkzeug und Werkstück und verfahrensbedingte Energieübertragung (trennend, umformend) wird ein Werkstück mit bestimmter Grundform in eine vorgegebene Form umgewandelt.*“; WECK, M., *Dubbel - Taschenbuch für den Maschinenbau*, 2005, p. T1.

In order to point out a number of non-distinctive features, the definitions do not claim any restrictive regulation e.g. concerning the processed material, mobility, or the size of the machine, thus opening room for a broad range of various machines which suits the definition.

1.1.1.12 Summary and conclusions

The introduction of the existing categorizing and definition on machine tools revealed that, according to its initial purpose, distinctions among the categories have been made due to different patterns, such as processing and technical features (DIN 8580, ISO 23125, PRODCOM classes), components including their mode of functioning (2006/42/EC), processed material (PRODCOM groups), etc.

Concerning DIN 8580, it is worth noticing, that some of the processes – even from different process classes - might be performed on the same machine tool, e.g. deep drawing (2.2.2) and severing (3.1), just by changing the tool. Therefore this classification according to DIN 8580 does not provide a clear and unambiguous basis to classify machine tools.

The EU directive on machinery at least gives a very broad definition of machinery, but does not provide any guidance, how to distinguish or classify machine tools as a subgroup of machinery. Hence, to resolve this deficiency, the definition on machine tools by Otto Kienzle as stated in 1.1.1.11 can be comprised as framework to gain a more precise picture of the term 'machine tools'.

PRODCOM provides a clearly arranged view on machine tools and other general machinery which could be subject to this study, besides supplying a multitude of market figures in order to gain a picture of the economic impact for each category. As mentioned afore, due to various facts, PRODCOM remains being an indispensable constituent when analyzing machine tools. However, it should be pointed out that the criterions by which machine tools have been defined as such and put into categories remain unknown,[25] and actually it is up to the manufacturer of machine tools to classify the products according to NACE. In comparison to the 'Red Book' issued by the VDW, it is obvious that PRODCOM provides solely aggregated figures for machine tools (given the complexity and multitude of different types of machine tools) which hamper the

[25] Note: Exemplarily, among exclusively cutting and forming machines, class 28.41 contains one casting machine (28.41.33.30 "Presses for moulding metallic powders by sintering [...]")

identification of environmentally significant machines. Subsequently, an unaltered transfer of the PRODCOM classification to the Product Group Study may lead to inconsistencies among the product scope. In order to cross-check our findings and sharpening the system's boundaries', further external data shall be involved not only for the definition of scope but also throughout the whole study. Additionally, individual data of PRODCOM categories, notably value, sold volume, shall be assessed by measures of quality in order to assess applicability and relevance for this study.

It remains to be emphasized that most existing definitions and classifications do not entirely match our aim to set a sound foundation for the on-going analysis of the study, considering that environmental aspects have not been part to any of them. Some are tailored to small part of machine tools (e.g. DIN EN ISO 23125 for turning machines) which is conflictive considering that it is intended to initially define a broad scope. On the other hand, some are defined in such broad terms (Directive 2006/42/EC on Machinery), for which further specification in reference to machine tools is required.

1.1.2 Definition of machine tools

1.1.2.1 Preliminary restrictions

In the first place, finding the product scope requires several confinements and assumptions. Due to the multitude of definitions and classifications, which differ in the degree if specification and applicability, it is reasonable to start out with a broad and qualitative approach as introduced in 1.1.1.11. Hence, by compiling implicit findings, we are capable to phrase several restrictions which help us defining an appropriate product scope for machine tools.

As argued in 1.1.1.11, the manufacturing process executed by a machine tool is liable to a certain objective, notably changing the geometric shape of a workpiece. In other words, the workpiece is obliged to have a geometric shape before and after the process, which has already been defined in 1935 by Koch and Kienzle and taken up later by Milberg and Weck. Comprising the Machinery Directive introduced in 1.1.1.4, as there is no obvious contrariness with the other qualitative approaches, the Kienzle/Milberg/Weck definition is compatible with this document, too.

- Restriction 1 (technology):

  Deriving from the above definitions, the following technologies subsequently have to be excluded:

- Although providing a geometric shape after the process, **primary shaped** components generally are vaporous, liquid, as well as paste-like or granulated during input, thus lacking a geometric shape. Hence, machinery for primary shaping will not be considered any further as “machine tools”.

- Considered on a microscopic level, **surface treatment and coating** as well as procedures **modifying material properties** may lead to a change of the geometric shape of a workpiece, although the intention is different. As this circumstance is rather a side effect of the process, these technologies deviate significantly from those of machine tools in a stricter sense: In the case of **blasting technologies** following considerations lead to the conclusion to exclude blasting technologies from the definition of “machine tools” in a stricter sense: Sandblasting machines are generally equipped for industrial cleaning tasks, such as the removal of contamination or coatings from surfaces. The process media differs with the specific field of application (e.g. suspensions of water, air, process gas and/or abrasives), but the process can also be non-mechanical (lasers). To mention two major differences to those machines which we have regarded so far, blasting machines cannot be considered as production machinery in a conventional sense. The environmental aspects (dust emissions, blasting media consumption and recycling) are different from those being relevant for typical metal working cutting and forming machine tools, hence feature other, very specific characteristics. From the economic perspective industrial cleaning in general becomes more important, however, blasting technologies rather play a minor role (approximately a share of 15% of all cleaning technologies)[26]. Regarding the environmental significance, from the manufacturers’ point of view, there is a trend towards clean technologies, expressed by a decline in chlorinated hydrocarbons based cleaning accompanied by an increasing demand for laser technologies,[27] All in all, it should be noted that blasting machinery will not be considered part of the scope, as sufficiently large technological similarities with machine tools cannot be stated

[26] KRIEG, M., *Markt- und Trendanalyse in der industriellen Teilereinigung*, Konferenzbeitrag.

[27] KRIEG, M., ref. 26.

(meaning that no reasonable comparability with other machines is given).

Furthermore, the premise of determined shapes curbs the operating mode of a machine, meaning that the premise of reproducibility has to be preserved. This leads to another restrictive assumption:

- Restriction 2 (product with reproducible geometry):

  Cutting tools for shredding and the like are considered out of scope as they do not grant a determined geometrical result.

The definition also curbs aspects of the workpiece's properties, implying another restriction:

- Restriction 3 (strength of shape):

  Picking up the concept of determined reproducible shapes, the stability of the workpiece remains being an important feature, though leading to the exclusion of **textile as well as rope-making machines** from the product scope, as the processed material is not in a solid, rigid state. This restriction applies to processed material/workpieces which are fluid, soft, very ductile, yielding, and the like, before, during, and after machining, meaning that gravitational, frictional, gripping, or joining forces or torques lead to a deformation in terms of compression, stretching, bending, twist, or volume change in one or several dimensions.[28]

Furthermore, as the focus of this study is meant to be on professional and industrial use of machine tools, DIY ("Do-it-yourself") power tools and the like should be excluded from the scope. DIY tools differ from professional equipment in such a way that they are not placed on the B2B market and cannot be considered as investment goods but rather as consumer goods. As they have to meet other, consumer market specific demands, DIY tools are designed substantially different from professional machine tools and thus are considered out of scope. Investment goods, on the other hand, are highly durable commodities used for creating and processing goods to generate added value. DIY tools do not entirely meet such requirements.

- Restriction 4 (operating a machine tool):

[28] Compare SCHNEIDER, B., *Prozesskettenorientierte Bereitstellung nicht formstabiler Bauteile,* 1999, p. 6. and GÖTZ, R., *Strukturierte Planung flexibel automatisierter Montagesysteme für flächige Bauteile*, 1991, p.21.

> **Tools portable by hand** are usually home-use tools and are characterised by rather short actual operating times.[29] Even those tools portable by hand, which are used by professionals usually are in operation only for few minutes per day, which is a totally different use pattern (and much lower total power consumption) than with large scale stationary machine tools.

Thus, machineries solely featuring one of the above mentioned restrictions will not be considered any further as “machine tools”.

Applying DIN 8580 as introduced in 1.1.1.1, in regard to restriction 1, the scope narrows to a number of few particular technologies. Processes, which are typically performed by machine tools that are those from the process groups 2 Forming, 3 Cutting, and 4 Joining and the respective sub-groups (marked in orange) with some exceptions: Blasting processes (2.2.6, 2.2.7, 3.3.6) are not performed with machine tools and so are disassembly (3.5), cleaning (3.6) and joining fabrics and textiles (4.9) processes, although the cleaning processes might be relevant for the environmental assessment: Required cleaning depends on the way the machine tool operates, e.g. lubricant cooling versus dry processing. There are some more processes, which are typically not performed by machine tools, but could be, such as thermal removal (3.4.1): Here it has to be carefully considered, that the same purpose might be served by machine tools or another kind of industrial equipment. Overlaps with lot 4 (industrial and laboratory furnaces and ovens) might be relevant in a few cases, where machine tools process workpieces under heated conditions. Scope related processes according to the DIN 8580 are shown in Figure1-5.

[29] See also the analysis of charging use patterns for power tools as outlined in Bio Intelligence Service, Fraunhofer IZM, CODDE: EuP Preparatory Study on Battery Chargers and External Power Suppliers, DG TREN Lot 7, 2007

Figure1-5: Machine Tools Scope – Overview Manufacturing Processes classified according to DIN 8580 (selection)

- <u>Restriction 5 (only entire systems)</u>: In order to find a sound definition of machine tools, at first, **single components and sub-assemblies** are expelled from the scope (for clarification: single components and sub-assemblies as parts of machine tools are in the scope when investigating improvement options etc., but not as a distinct definition criterion of what defines a machine tool).[30]

- Restriction 6 (no supply and disposal systems): Besides components, **supply and disposal systems** are out of scope, such as central cooling lubricant systems, as they only affect the periphery of our system. Although being in a functional coherency with machine tools, they should not be covered by the definition of machine tools as they are solely capable to supply border functions in the manufacturing process. Nevertheless, impacts of these supply and disposal systems on machine tools and vice versa will be considered when assessing environmental impacts and systems correlations.

1.1.2.2 Generic definition of machine tools

Summarizing the considerations above, taking the machinery directive as a frame work and Kienzle's technical definition as a straight-forward definition for machine tools, the proposed definition of the scope of this study reads as follows:

A machine tool is a stationary or transportable assembly, which is neither portable by hand nor mobile, and which is dependent on energy input (such as electricity from the grid or stand-alone / back-up power sources, hydraulic or pneumatic power supply, but not solely manually operated) when in operation, and consists of linked parts or components, at least one of which moves, and which are joined together for a specific application, which is the geometric shaping of workpieces made of arbitrary materials using appropriate tools and forming, cutting, physico-chemical processing or joining technologies, the use of which results in a product of defined reproducible geometry, and intended for professional use.

Machine tools comprise exemplarily:

- *machine tools for separating / cutting and forming of metals, including those using a laser beam, ultrasonic waves, plasma arc, magnetic pulse, electrolytic etching, etc.*
- *machine tools for turning, drilling, milling, shaping, planing, boring, grinding etc.*

[30] Concerning the PRODCOM database, the sold volume for single components is measured in kg and therefore exacerbating its comparability to other categories, which are usually measured in number of items.

- *stamping or pressing machine tools*
- *punch presses, hydraulic presses, hydraulic brakes, drop hammers, forging machines etc.*
- *draw-benches, thread rollers or machines for working wires*
- *machine tools for working wood, cork, bone, hard rubber, hard plastics, cold glass etc., including those using a laser beam, ultrasonic waves, plasma arc, magnetic pulse etc.*
- *stationary machines for nailing, stapling, gluing or otherwise assembling wood, cork, bone, hard rubber or plastics etc.*
- *stationary rotary or rotary percussion drills, filing machines, riveters, sheet metal cutters etc.*

Transportable assemblies are understood to be in operation at changing locations, but parts or the whole assembly are

- *floor standing or*
- *fixed to any other fixed installation (e.g. table top devices)*

while in operation.

"Portable by hand" refers to devices, which are completely carried by the operator when in use.

"Mobile" refers to machinery equipped with a motor

- *to be re-located as a whole or*
- *to process any material while being in motion as a whole*

and are excluded from scope.

Equipment, where only parts of the device are hand-held in operation, but other physically connected parts are stationary, floor standing or fixed to any other fixed installation, are considered stationary or transportable as a whole.

Equipment, being typically powered by internal batteries when being in operation is out of the scope.

The condition "product of defined reproducible geometry" explicitly excludes all machinery processing animal or human material (medical and food processing equipment), textiles manufacturing and processing, and shredding equipment.

"Related machinery" is machinery for professional use, which contains components and modules of other machinery, which are similar to those used in machine tools. For clarification: these components and modules might be used in machines, which do not fall under the definition of machine tools as provided above.

Ecodesign aspects of machine tools and related machinery being in the scope of the study cover also machine external components as far as the operation and design of the machine tool could have an effect on this external equipment (workpiece preparation, centralised lubricant supply, cleaning processes etc.). However, the direct optimisation of these external components is not in the scope of the study.

The following subchapters reflect the definition of machine tools against the common understanding of machinery and equipment in the branches:

- metal working machine tools,
- wood working machinery and
- welding, soldering and brazing machines,

However, this explicitly does not mean a restriction of the scope to these three sub-branches only. Others are covered as well by the broader definition provided above.

1.1.2.3 Metal working machine tools

CECIMO, representing national machine tool associations from 15 different nations in Europe, consider machine tools primarily, but not only, as devices for forming and cutting metals.[31] As another outstanding feature, CECIMO defines machine tools as machineries to manufacture products or parts, generally prepared for subsequent treatment in highly complex and sophisticated end-products such as airplanes, medical devices, and the like.[32] Subsequently, the specific scope of metal working machine tools shall be restricted solely to those in the spectrum of the B2B ("business-to-business")

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[31] See http://www.cecimo.eu/index.php/discover-machine/machinetoolsineverydaylife.html [cited 17.10.2010].

[32] See http://www.cecimo.eu/index.php/discover-machine/whatitisamachinetool.html [cited 17.10.2010].

market. In this regard, a CECIMO definition of a metal working machine, which is broadly accepted among the industry, reads as follows:

A metal working machine tool is a power driven, not portable by hand, powered by an external source of energy, designed specifically for metal working either by cutting, forming, physico-chemical processing, or a combination of these techniques.

To stay within the wording of our general definition, aspects deriving from CECIMO's definition shall be incorporated. A corresponding definition tailored to metal working machine tools reads as follows:

A metal working machine tool is a stationary or transportable, but not portable by hand or mobile assembly, connected to the power grid when in operation, consisting of linked parts or components, at least one of which moves, and which are joined together for a specific application, which is the geometric shaping of workpieces made of metallic materials either by cutting, forming, physic-chemical processing, or a combination of these techniques, using appropriate tools, resulting in a product of defined geometry.

1.1.2.4 Wood working machines

In analogy to metal machining, manufacturers of **wood working machines** are organized as a self-contained industry sector and are also covered by the scope of this Product Group Study. Woodworking machinery is deployed at all stages of processing wood, beginning with the local cutting of wood of felled trees up to fine machining of single products. Unlike metal working, there is a considerable B2C ("business-to-consumer") market not covered by the scope of the study for wood working machines, primarily a broad range of handheld machines as well as transportable motor operated circular saws and band saws. However, there is a wide range of machines on the B2B market, which use similar technologies (e.g. cutting, planing, milling, grinding) and are equipped with automation. These products are considerably different from B2C products regarding performance, weight, and cost constraints. Subsequently, the definition states the following:

A wood working machine is a stationary or transportable, but not portable by hand or mobile assembly, connected to the power grid when in operation, consisting of linked parts or components, at least one of which moves, and which are joined together for a specific application, which is the geometric shaping of workpieces made of wooden materials using appropriate tools and technologies, resulting in a product of defined geometry.

1.1.2.5 Welding, soldering, and brazing machines

Besides using a material related approach to distinguish among industrial branches, it is worthwhile to focus on joining machinery, notably **welding, brazing and soldering machines.** According to Kinkel and Lay,[33] more than two thirds of the German metal and electrical industry are using methods for joining, whereby 60% of these companies expect an increasing importance of the technology for the future. Besides adhesive bonding, welding and soldering are one of the most crucial technologies for industrial manufacturing, whereas the latter is of special importance for electrical engineering and the manufacture of electrical devices. The outstanding role of joining technologies in production processes justifies an isolated analysis, and also due to economic and technological differences compared to metal and woodworking machine tools.

It is acknowledged, that the European Welding Association does consider manual welding equipment not being machinery in the sense of the machinery directive[34]:

- Equipment for manual arc welding and allied processes is intended to be moved by a welder (human force) and therefore is not a machine: The Machinery Directive is not applicable to arc welding equipment for manual welding.
- Equipment for manual arc welding and allied processes intended to be incorporated in a mechanized system is not a „partly completed machine“ but a part of a machine only: The Machinery Directive is not applicable to arc welding equipment to be incorporated in a mechanized system.

However, the machinery directive does not constitute the legal framework of this study, hence other energy-using products, such as manual welding equipment are potentially in the scope of this study.

Following the definition of welding by the American Welding Society (AWS)[35], welding machines are defined as follows:

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33 KINKEL, S., LAY, G., *Technologietrends in der Produktion – Praxis der Anlagenmodernisierung in der deutschen Metall- und Elektroindustrie*, 2006, p.3.

34 Resolution of EWA October 27, 2008

35 Adapted from JEFFUS, L., BOWER, L., *Welding Skills, Processes and Practices for Entry-Level Welders, Book 1*, 2009, p. 4.

A welding machine is a stationary or transportable, but not portable by hand or mobile assembly, connected to the power grid when in operation, consisting of linked parts or components, at least one of which moves, and which are joined together for a specific application, which is producing coalescence of arbitrary materials by heating them to the welding temperature, with or without the application of pressure or by the application of pressure alone, and with or without the use of filler metal, using appropriate tools and technologies, resulting in a product of defined geometry.

1.1.3 Classification of product scope

- **Objective**

In accordance with our definition on machine tools and also demanded by the tender specifications for the Product Group Study on machine tools,[36] the scope is ought to be determined in terms of PRODCOM categories. This way, the scope can be specified in terms of particular machines in conjunction with the related annual production figures (average unit value, sold volume, and turnover).

The classification constitutes a significant foundation for on-going analysis, especially in regard to the economic analysis in task 2, which means that a reliable basis needs to be created.

- **Limitations**

In regard to the classification pattern of PRODCOM, there are certain limitations worth to be indicated which are hampering the accurate allocation of categories to the definition. Considering that a broad variety of machines are addressed by our definition, the level of detail for particular types of machines regarding number of categories, comprised machines within one category, specification of the category's description, and the like, is quiet heterogeneous. In some cases, it is not unambiguously acknowledged that the definition fits to the comprised machines of several categories (e.g. 28.99.39.53 "Other machinery for earth, stone, ores, etc., n.e.c.").

This means that although certain categories can be allocated to the aforementioned machines, the selection is ought to be perceived rather as an indication of machines

[36] EUROPEAN COMMISSION, ref 1, p. 24f.

included in the product scope, also in regard to that data input is mandatory for the economical assessment coming in task 2.[37]

1.1.3.1 Metal working machine tools

In regard to metal working machine tools, a substantial and differentiated base is provided for the on-going course of the analysis. 59 categories are summarized in class 28.41 “Manufacture of metal forming machinery”.

Using the aforementioned definition of metal working machine tools, PRODCOM class 28.41 “Manufacture of metal forming machinery” will be reviewed in order to find appropriate categories.[38] Hence, **54** out of 59 categories are identified in terms of the definition (see Table 4-1, p. 143). However, certain categories from this class are excluded due to the violation of specific restrictions, which is described briefly in Table 1-6.

Table 1-6: Expelled Categories from class “28.41 - Manufacture of metal forming machinery”

Expelled category	Applicable restriction
28.41.22.33 - Way-type unit heads for working metal by drilling, boring, milling, threading or tapping	5 (Only Entire Systems)[39]
28.41.33.30 - Presses for moulding metallic powders by sintering or for compressing scrap metal into bales	3 (strength of shape not given); 2 (no products/parts being manufactured)
28.41.40.30 - Parts and accessories for metal cutting machine tools (excluding tool holders and self-opening dieheads, work holders, dividing heads and other special attachments for machine-tools)	5 (Only Entire Systems)
28.41.40.50 - Parts and accessories for metal forming machine-tools (excluding tool holders and self-opening dieheads, work holders, dividing heads and other special attachments for machine-tools)	5 (Only Entire Systems)
28.41.40.70 - Parts and accessories for machine-tools operated by ultrasonic processes	5 (Only Entire Systems)

[37] Note: The issue of market data provided by PRODCOM will be raised briefly in the environmental screening and discussed in detail in task 2.

[38] Due to material related restraints as argued in 0, other PRODCOM classes can be excluded a priori.

[39] Note: Single components and sub-assemblies as parts of machine tools are in the scope when investigating improvement options etc.

A non-exhaustive record of typical metal working machine tools affected by the definition stated above is depicted in Table 1-7.

Table 1-7: Non-exhaustive list of comprised metal working machine tools

Metal working industry - comprised machine tools
• Broaching machines • Deburring machines • Draw-benches • Electro-chemical, electron-beam, ionic-beam or plasma arc machines • Electro-discharge machines • Gear cutting/grinding/finishing machines • Grinding machines • Honing machines • Horizontal machining centres • Hydraulic presses • Lapping machines • Laser/light/photon beam machines • Lathes • Multi-station transfer machines • Non-hydraulic presses • Non-numerically controlled bending machines • Non-numerically controlled boring machines • Non-numerically controlled boring-milling machines • Non-numerically controlled cylindrical surface grinding machines • Non-numerically controlled die stamping machines • Non-numerically controlled drilling machines • Non-numerically controlled flat-surface grinding machines • Non-numerically controlled flattening machines • Non-numerically controlled folding machines • Non-numerically controlled forging machines • Non-numerically controlled horizontal lathes • Non-numerically controlled milling machines • Non-numerically controlled notching machines • Non-numerically controlled presses • Non-numerically controlled punching machines • Non-numerically controlled sharpening machines • Non-numerically controlled shearing machines • Non-numerically controlled straightening machines • Numerically controlled automatic lathes • Numerically controlled bending machines • Numerically controlled boring machines • Numerically controlled boring-milling machines • Numerically controlled cylindrical surface grinding machines • Numerically controlled drilling machines • Numerically controlled flat-surface grinding machines • Numerically controlled flattening machines • Numerically controlled folding machines • Numerically controlled grinding machine • Numerically controlled horizontal lathes • Numerically controlled knee-type milling machines

- Numerically controlled milling machines
- Numerically controlled notching die stamping machines
- Numerically controlled notching forging machines
- Numerically controlled notching machines
- Numerically controlled plano-milling machines
- Numerically controlled punching machines
- Numerically controlled sharpening machines
- Numerically controlled shearing machines
- Numerically controlled straightening machines
- Numerically controlled tool-milling machines
- Numerically controlled turning centres
- Planing machines
- Press machines
- Riveting machines
- Sawing/cutting-off machines
- Shaping machines
- Slotting machines
- Spinning lathes
- Swaging machines
- Tapping machines
- Thread rolling machines
- Threading machines
- Turning centres
- Ultrasonic machines for semiconductor devices
- Unit construction machines (single station)
- Vertical machining centres
- Wire producing machines

1.1.3.2 Woodworking machines

Whereas the range of categories for metal working machine tools is comparatively broad, the differentiation of woodworking machines is less detailed, split in only 11 categories, which also include machinery for processing other materials (cork, bone, hard rubber, hard plastic, and others). However, although labelled differently, it is acknowledged by sectoral experts that manufacturers from the plastic and food machinery industry do not report to these categories, therefore they comprise wood and cork machining in their vast majority only. Accordingly, the **11** aforementioned categories substantiate the product scope for woodworking machines (see Table 4-2, p. 145).

A non-exhaustive record of typical woodworking machines affected by the definition stated above is depicted in Table 1-8.

Table 1-8: Non-exhaustive list of comprised woodworking machines

Woodworking industry - comprised machine tools
• Band saws • Bending machines • Boring machines • Circular saws (stationary) • Crosscut machines • Cut-off saws • Drill machines • Drilling machines • Grinding machines • Horizontal band saws (stationary) • Lathes • Milling machines • Mortising machines • Moulding (by cutting) machines • Multi-purpose/universal machines • Panel dimension saws • Panel saw • Paring machines • Planing machines • Polishing machines • Presses • Radial arm saws • Ripsaws • Router machines • Saw benches • Sawing machines • Slicing machines • Spindle moulder/wood shaper • Splitting machines • Surface planer • Tenoners • Thickness planer • Vertical band saws (stationary)

1.1.3.3 Welding, soldering, and brazing machines

Welding, soldering, and brazing equipment is dominated by a multitude of smaller devices, which are typically transportable. Only very few units are actually integrated in a stationary machine. Table 1-9 lists welding, soldering and brazing machinery and equipment following the PRODCOM wording. Several more similar categories are clearly units portable by hand or parts and components. Actually **9** PRODCOM categories are relevant for this study.

Table 1-9: Non-exhaustive list of comprised welding, soldering, and brazing machines

Welding, soldering, brazing industry - comprised machine tools
• Electric brazing or soldering machines and apparatus • Electric machines and apparatus for resistance welding of metal • Fully or partly automatic electric machines for arc welding of metals (including plasma arc) • Manual welding with coated electrodes • Shielded arc welding • Machines and apparatus for spraying of metals • Machines and apparatus for resistance welding of plastics • Machinery and apparatus for soldering, brazing, welding or surface tempering

1.1.3.4 Other machine tools

Besides the types of machines which have been already classified above, further machines can be identified by the aid of the generic definition as stated in 1.1.2.2.

In the course of classifying other machine tools, **10** categories were identified, deriving from several different industry branches (illustrated in Table 1-10). A definition of these in terms of categories only provides little insights concerning the variety of products or the market relevance, which is due to the merging of different types of machineries (e.g. merging of stone, ceramics, glass, and the like) and also the high level of aggregation (e.g. 28.49.11.70 comprises all kinds of machine tools but three specific types). It is striking, that there is a strong similarity to metal working machine tools regarding the manufacturing processes, which are cutting primarily (sawing, grinding, polishing, splitting, etc.) and forming (bending, pressing, etc.). For details, see Table 4-4, p. 146.

Table 1-10: Non-exhaustive list of affected industries for other machine tools (indication).

Comprised other machine tools
Machines for the ceramics industry • General purpose machinery • Grinding machineries • Polishing machineries • Sawing machineries
Machines for the construction industry • Grinding machineries (stone, concrete, etc) • Polishing machineries (stone, concrete, etc) • Sawing machineries (stone, concrete, etc)
Machines for the glass industry • Grinding machineries • Polishing machineries • Sawing machineries
Machines for the plastic & rubber industry • Assembling machineries • Band saws • Bending machineries

- Calendaring machineries
- Circular saws
- Cutting machineries
- Drilling machineries
- Grinding machineries
- Milling machineries
- Morticing machineries
- Moulding (by cutting) machineries
- Multi-purpose machineries
- Multi-purpose machineries
- Paring machineries
- Peeling machineries
- Planing machineries
- Polishing machineries
- Presses
- Rolling machineries
- Sawing machineries
- Size reduction machinery
- Slicing machineries
- Splitting machineries
- Splitting machineries

Machines for the recycling industry

- Scrap metal presses

1.1.3.5 Summary and conclusions

In the course of classifying the product scope, all in all **84 categories** have been identified which substantiate the scope for this study. For the detailed breakdown, see Table 1-11.

Table 1-11: Summary of product scope classification

Type of machine tool	Number of comprised categories		Usability for following tasks[40]
Metal working	54		good usability (detailed breakdown of metal working machine tools (distinction between NC, non-NC; mostly according to manufacturing technology)
Woodworking	11		Specification required (only few categories existent; mixed with other machine tools; no distinction between complex and simple woodworking machines)
Welding, soldering,	9		moderate usability (however, this includes largely

[40] Note: Economic figures are not part of the evaluation.

brazing			a segment of smaller units, partly for integration in other machines, but not machinery as such)
Other machine tools	10		Partly usable (mix of all kind of machines; high level of aggregation; unspecific description of several categories)
Total:	84		

1.1.4 Related machinery

Besides the identification of machine tools, it is additionally intended to follow a modular approach. This is due to the fact that when discussing technological improvement options, the machine sooner or later needs to be regarded in terms of its single modules in order to localize environmentally significant aspects and their corresponding improvement potential. As a consequence for defining the product scope, machines will be included which contain modules similar to those typically used also in machine tools. However, this means that not the whole machine is analysed, but the identified module is subject of further considerations.

1.1.4.1 Modular design of machine tools

In order to reduce the level of complexity, this approach describes machine tools in terms of their single ingredients, in the following referred to as 'modules'. This approach should improve transparency of the ecological profile of machines and support the identification of improvement potential.

With a view to existing literature, however, there is neither an unambiguous definition for machine tool modules nor a 'typical set' of modules.

According to ISO/NP 14955, the view on machine tool components is restricted to those which consume electrical energy. This specific view derives from the intended ISO approach to concentrate on improving the electrical energy efficiency during the use phase. Machine components are defined as "mechanical, electrical, hydraulic, or pneumatic device(s) of a machine tool, or a combination thereof".[41] The manufacturer who applies ISO/NP 14955 for his products has to specify incorporated modules and select the associated functions individually for each machine. However, it should be mentioned that according to the standard the idea of modules is predominantly functionally-oriented (details provided in section 1.2.6).

In the frame of this study, modules are seen in a broader sense, with the intention to concentrate later on those which contain a significant improvement potential. Thus, in this context, the term modules refer to per se autonomous subsystems which in combination form to a greater system, in which the individual functions (e.g. acceleration, lubrication, vibration damping, etc.) are necessary and contribute to the overall value-adding process (namely the manufacturing of a product). This implies that modules consist of both functional as well as physical features.

The authors of the study support the idea that it is difficult to define a generic set of typical machine tool modules, considering the manifoldness of machine tools as identified in the previous section. However, in order to identify the ecological impact and improvement potential, it is necessary to restrict and generalize 'typical modules' to conduct further analysis. Thus, from a physical point of view, standard modules of machine tools are:

- **frame** (cast iron)
- **guides and bearings** (guides: motion control & adjusting guide (both linear and circular), bearings: hydrostatic, (axial) electrical, etc.)
- **main drives** (electric main drives (e.g. motor spindles for lathes and milling machines, direct current motors, synchronous motors, etc.), hydraulic main drives)
- **feed drives** (hydraulic feed drives for lathes, milling machines, etc.)
- **control device** (CNC applications)
- **hydraulic unit** (continuously variable linear drives)
- **pneumatic unit** (sealing air, workpiece clamping, workpiece holding)

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41 INTERNATIONAL ORGANIZATION FOR STANDARDIZATION (ISO), *Draft for ISO/CD 14955-1 – Machine Tools – Environmental evaluation of machine tools – Part 1: Design methodology for energy-efficient machine tools,* 2011, p.4.

- **cooling / cooling lubricant unit** (closed circuits for cooling tool and workpiece mainly, using typical lubricants for machine tool processes)
- **process media supply** (welding wire and gas, laser system)
- **Power supply** (electric power transformation)

As far as functionalities of machine tools are concerned, CECIMO in their SRI concept defines the following distinction:

1. Control function
    a. CNC
2. Assisting functions
    a. Process lubrication cooling
    b. Chip removal
    c. Mist removal
    d. Cooling
3. Set up functions
    a. Part handling / part clamping
    b. Tool handling / tool clamping
    c. Process media supply & maintenance
4. Shape of part transformation functions
    a. Manufacturing process integration
    b. Part / tool relative motion
    c. Transforming energy supply

Slightly deviating from this distinction, generalized functions according to ISO/NP 14955 comprises machining (machining process, motion and control), process conditioning and cooling, workpiece handling, tool handling or die change, recyclables and waste handling, and machine cooling/heating.[42] These can be further subdivided into sub functions to detect relevant energy consumers.[43]

Both aspects are important: How to optimise the various components of a machine tool and how to realise certain functions of a machine tool in the most appropriate way. Overarching systems improvement aspects need to be addressed as well. **Table 1-12** correlates physical modules of a machine tool with functional modules of a machine tool. Some physical modules are potentially related with more than one function and vice versa. Some functions might be realised only very occasionally with a marked physical unit (such as the rare use of pneumatics seen in machine tools).

By incorporating the modular approach into the study, the distinction between highly relevant modules from less important ones is facilitated, which is of great significance when identifying BATs for improving the overall environmental compatibility of machine tools. Also a modular approach provides the opportunity to achieve machine-independent findings, considering the fact that most modules can be accommodated in all kinds of energy using products beyond machine tools.

Note, that the above definitions of ‘modules’ is meant to indicate the classification of modules followed in this study. Neither in literature nor in the legislation there is yet a definition of modules available, with qualifies as a definition in legal terms. Such definitions, clarifying in particular unambiguously the system boundaries of each relevant module, still have to be developed, if required for legislative requirements.

[42] ISO, ref 41, p. 9.

[43] ISO, ref 41, p. 12.

Table 1-12: Matrix comparison of machinery modules and functional modules (according to CECIMO SRI)

	Control Function	Assisting functions				Set up functions			Shape of part transformation functions		
	CNC	Process lubrication cooling	Chip removal	Mist removal	Cooling	Part handling / part clamping	Tool handling / tool clamping	Process media supply & maintenance	Manufacturing process integration	Part / tool relative motion	Transforming energy supply
Frame											
Guides and bearings						x	x				
Main drives										x	
Feed drives						x	x				
Control device	x										
Hydraulic unit						x	x			x	
Pneumatic unit						x	x				
Cooling / cooling lubricant unit		x	x	x	x						
Process media supply								x			
Power supply											x
remarks									Systems aspect		

1.1.4.2 Environmental relevancy of selected modules

The modular approach with regard to its single components provides the opportunity to gain a more comprehensive and detailed impression of the environmental relevancy.

The **frame** of a machine tool ensures a stable and precise process and conducts processing forces into the machine frame. Typical frames are castings from gray cast iron and welded steel constructions. For large machines, moreover, the frame has to be anchored on a concrete foundation, in order to balance dynamic forces during operation. In reference to the environmental relevancy, fields of optimisation are solely given in the manufacturing phase, e.g. due to substitution of said materials with alternatives such as metal foam. In regard to material-efficiency, reductions can be achieved e.g. by the use of technologies for analyzing load curves. This way, the overall ecological efficiency of machine tools can be improved due to a lower extent of consumption of material and energy. Considering the concrete foundation, due to a lack of alternatives, less potential for improvement is given.[44]

Guides and bearings are essential to reduce machine-specific motions to a determined set of degrees of freedom. This broadly approached array is of particular significance regarding energy consumption and losses during operation time. The efficiency of motions is primarily hampered by friction, thus low friction, avoidance of stick-slip-effects, and the selection of wear-resistant components have a positive effect on energy efficiency. High friction is also caused by self-locking gearboxes, which are usually applied for many machine tools. Moreover, the acceleration of masses resembles a critical feature, as it significantly contributes to the overall energy consumption. Considering that guides and bearings are of special importance to several components of machine tools (main and feed spindles, work piece table to mention the most relevant), potential for improvement measures and solutions on a broad range can be anticipated.

Main and feed drives for machine tools are usually powered by electric motors, coming to the fore in compressors, pumps, and spindles. In regard to task 1.3, eco efficiency requirements have already been phrased on a legislative level, notably by Commission Regulation (EC) No 640/2009 on ecodesign requirements for electric motors.

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[44] Note: Another approach to reduce emphasis on the foundation would be to find ways to reduce dynamic forces, respectively find other channels for redirection.

However, as the regulation does not cover the full spectrum of motors used in machine tools, it is worthwhile identifying further types of relevant electric motors. Besides raising the electrical efficiency, in reference to CECIMOs' draft on the Self-Regulatory Initiative, however, enhancements can be achieved in the field of regenerative feedback of breaking energy or by upgrading to greater inverter units and motors due to reduced losses.

Accordingly, **control devices, hydraulic units and cooling / cooling lubricant units** provide considerable potential e.g. to elevate the energy efficiency on a higher level. In this regard, CECIMO proposes several options, such as standby modes during non-operation or improved energy-fit modes according to the tangible need of energy for the process.

Pneumatics is occasionally employed in various types of machine tools and production machinery in general, e.g. in the form of sealing air, workpiece or tool clamping. Losses within pneumatic systems occur due to various reasons, in particular during the integration (assembly) of pneumatic systems into greater systems respectively machine tools. These are gas leakages due to improper clipping of air tubes, unnecessary windings and bends of pneumatic feeds, etc. Skilled installation of pneumatic devices, however, significantly increases the efficiency of pneumatics. Application specific design and dimensioning in combination with volume flow monitoring and adaptable operation modes during processing supports a minimized need for electric energy. A decline in flow rate, for example, indicates the occurrence of leakages, which can be fixed short in time if constant monitoring is applied.

Process media supply is relevant for selected processes, such as welding with a welding wire or processes, where process gases are used, welding and laser cutting systems being the most relevant one.

Power supply covers transformation of electric power for the various modules of the machine tool. As every power transformation is related to power losses, the efficiency of the transformer or power electronics components and circuitry under various load conditions is a key aspect for reducing the overall power consumption of the machinery.

Summarizing our findings, though, a distinction between more or less important components is hampered at this stage of study, but can be substantiated in the later course of the study when discussing base cases and options for improvements.

1.1.4.3 Non-exhaustive identification of related machineries

As far as the related machineries are concerned, a non-exhaustive list can be presented, taking into consideration that a complete, definite identification of all machineries which are placed in the market and obtain common machine tools modules is impossible. Later in the study, statements will be made to which extend the findings on the module level can be extrapolated to other machinery segments, or whether there are severe limitations for any such transfer of findings[45]. Hence, by the help of PRODCOM division 28 “Manufacture of machinery and equipment n.e.c.”, an indicative and non-exhaustive list of industrial machinery, which might make use of modules similar to those used in “machine tools” is provided in **Table 1-13**. Machineries have been selected by means of the modules as described above with the exception of frames as well as guides and bearings. Due to the fact that frames can be found in various machines made of arbitrary materials and serving diverse purposes in the context of the product, it would lead to a broad product scope going beyond the capacities of the study. Same argumentation is applicable for guides and bearings, as they are indispensable and provide numerous layouts in every kind of machine.

By means of the Commission Regulation (EC) No 640/2009 on ecodesign requirements for electric motors, several machineries – which have been solely identified due to main and feed drive likeness and are covered by the Commission Regulation – can be excluded in the first place, namely those falling under NACE class 28.93 “Manufacture of machinery for food, beverage and tobacco processing”.[46] Furthermore, machines which exceed the range of capacity (thus, modules are dimensioned for other loads) typically found in machine tools will be out of focus, such as NACE class 28.22 “Manufacture of lifting and handling equipment” and 28.91 “Manufacture of machinery for metallurgy“. Main and feed drives findable in NACE group 28.3 “Manufacture of agricultural and forestry machinery” do not have any similarity with those in machine tools, due to the fact that combustion engines are generally deployed.

[45] This transferability depends also on the level of detail regarding specific improvement options identified as a very specific technological improvement might be applicable only to a very limited number of specific cases whereas a rather generic option (example for illustration only: “document measures taken to select motors of optimal size and performance for the intended application”) is transferable to a much broader range of applications

[46] Also categories 28.29.22.30 “Steam or sand blasting machines and similar jet-projecting machines (excluding fire extinguishers, spray guns and similar appliances)”, 28.94.22.50 “Dry cleaning machines”.

A non-exhaustive summary of machines with modular overlaps is depicted in Annex III – Related machinery (identified modules) (non-exhaustive) (**Table 5-1**, p.148). It should be mentioned that category 28.41.33.30, which is excluded from being considered "machine tool" (see Table 1-6) is covered on the module level as a "related machinery" due to similarities in modular design. Despite the fact that machines are being addressed, it should be pointed out that primarily the **manufacturer of system components** are affected by the extension of the product scope.

Table 1-13: Non-exhaustive list of affected industries for related machinery (indication).

Comprised machinery on a modular level
Machines for the chemical industry • Reactive resins machinery • Foam machineries • Floor covering machinery **Machines for the electronic industry** • Boules manufacturing machinery • Circuit machinery • Semiconductor manufacturing machinery • Ultrasonic machinery • Wafers manufacturing machinery • Cable machineries **Machines for the flat panel industry** • Flat panel display machinery **Machines for the glass industry** • Cleaning or drying bottles machinery **Machines for the lamp industry** • Machineries for assembling lamps **Machines for the packaging industry** • Capsuling machinery • Closing machinery • Labelling machinery • Machinery for aerating beverages • Machinery for filling • Packing machinery • Sealing machinery • Wrapping machinery **Machines for the paper & printing industry** • Collating machineries for books • Combined reel slitting cutting machineries • Combined re-reeling cutting machineries • Cross cutting machineries • Flexographic printing machinery • Folding machineries for books • Gathering machineries for books • Gravure printing machinery • Guillotines

- Machineries for making bags, sacks or envelopes
- Machineries for making cartons, boxes, etc.
- Moulding machineries
- Machinery for finishing paper or paperboard
- Paper or paperboard machinery
- Printing blocks and plates machinery
- Pulp making machinery
- Reel fed letterpress printing machinery
- Reel fed offset printing machinery
- Sewing machineries for books
- Slitting machineries
- Stapling machineries for books
- Type-setting machinery
- Unsewn (perfect) binding machineries for books
- Wire stitching machineries for books

Machines for the plastic & rubber industry[47]

- Blow-moulding machineries
- Calendaring machineries
- Extruders
- Injection-moulding machineries
- Sanding machineries
- Thermoforming machineries
- Tyre machinery
- Vacuum-moulding machineries

Machines for the textile industry

- Bleaching machineries
- Circular knitting machinery
- coating machinery
- Cutting machinery
- Doubling machinery
- Drawing machinery
- Dressing machinery
- Drying machinery
- Dyeing machineries
- Extruding machinery
- Finishing machinery
- flat knitting machinery
- Folding machinery (textile fabrics)
- Gimped yarn, tulle, lace, embroidery, trimmings, braid or net machineries
- Impregnating machinery
- Ironing machineries
- Laundry-type Washing machineries
- Nonwoven machinery
- Pinking machinery (textile fabrics)

[47] As plastics and rubber machinery constitutes a particularly relevant market segment with anticipated similarities to "machine tools" this market segment was screened to analyse, whether they should be regarded as "machine tools", "related machinery" or they do not fall under the scope of the study at all. This screening is provided below.

- Presses
- Printing machinery for printing textile materials
- Reeling machinery
- Reeling machinery (textile fabrics)
- Rope machineries
- Spinning machinery
- Stitch-bonding machinery
- Textile fibres machinery
- Texturing machinery
- Tufting machinery
- Twisting machinery
- Unreeling machinery (textile fabrics)
- Warp knitting machinery
- Washing machineries
- Weaving machinery
- Winding machinery
- Wringing machinery

1.1.5 Environmental screening of product scope

1.1.5.1 Working Plan Study – Plausibility Check

The 2007 Working Plan Study by EPTA covered under Machine Tools on the PRODCOM level basically metal working and wood working in one category, stone and ceramics working machine tools in another one, and separately welding equipment and the like.

1.1.5.1.1 Metal and Wood Working Machine Tools

The 2007 Working Plan Study provides an environmental screening of machine tools (named "Tool Machines" in the study), based on MEEuP[48]. For the on-going procedure of this study, especially in regard to our own assessment, comparisons with results of other studies are of particular interest.

The input parameters and the results of the assessment of the Working Plan study are as listed below, including comments from a first screening of the product group by Fraunhofer. Note, that this screening reflects the status of the study findings in a very early stage of the study. Later findings of the study overrule these data. The data below

48 VHK VAN HOLSTEJIN EN KEMNA BV, *Methodology Study Eco-Design of Energy-using Products (MEEuP)*, 2005.

is stated only to document the intermediate state of the study at this point and is NOT used for any further calculations in this study, nor should they be cited as results of the study. More accurate data is to be found in later task reports, see cross-references.

Table 1-14: Working Plan Study Plausibility Check – Metal, Wood and Stone / Ceramics Working Machine Tools[49]

Machine Tools (source: EPTA)		Screening by Fraunhofer (as of Dec 2010)	Data updates in later task reports
Estimated composition of Manufacture	total weight 300 kg - average of 100kg to 500kg; steel, electric motor (75%steel, 15%Cu, 5%Al), Display	This might be correct for some transportable machine tools, but this underestimates the weight of industrial type stationary metal working machine tools	See bill-of-materials for 9 Base Cases in Task 4 (4.1.1)
Stock [1.000 units]	7850,86	Stating a stock of several million units in the EU27 is a plausible order of magnitude Estimates: • Metal working machine tools: 2 – 3 million • Wood working machine tools: 1 – 2 million Other machine tools not considered for this screening	See detailed stock model in Task 2
Estimated electricity consumption [kWh/h]	50	Appropriate for larger metal working machine tools, not for smaller (transportable) ones (frequently wood working and machine tools); rough assumption for typical power consumption: • Metal working machine tools: 25 kW (CNC), 10 kW (smaller units); approximation avrg. 12 kW • Wood working machine tools: 10 kW	See use phase scenarios for 9 Base Cases in Task 4 (4.1.3)
Estimated use time per year [hours]	4240	Appropriate for larger machine tools used e.g. in the automotive industry as one dominating target sector for machine tools, not for those wood working machine tools operated by crafts shops (less working time than 16 hours per day and not running full time during working hours); assump-	See use phase scenarios for 9 Base Cases in Task 4 (4.1.3)
Estimated Use Pattern	16h*265days		See use phase scenarios for 9 Base Cases in Task 4 (4.1.3)

49 Note: The screening was primarily performed for categories deriving from group 28.4 "Manufacture of metal forming machinery and machine tools", results were revised based on plausibility check against EuroStat sector consumption data

Machine Tools (source: EPTA)		Screening by Fraunhofer (as of Dec 2010)	Data updates in later task reports
		tions: • Metal working machine tools (1-2 shifts per day): avrg. 3180 h/year, 12h*265days • Wood working machine tools: 4 h/day, 1,000 hours/year	
Estimations electricity consumption use for 1 year [kWh]	$2{,}12 \cdot 10^{5}$	• Metal working machine tools: $4 \cdot 10^{4}$ kWh/year • Wood working machine tools: $1 \cdot 10^{4}$ kWh/year	See Base Case results in Task 4 (4.3)
Total electricity consumption [kWh]	$3{,}14 \cdot 10^{11}$	Electricity: • Metal working machine tools: $7{,}5\text{-}11 \cdot 10^{10}$ kWh/year • Wood working machine tools: $1\text{-}2 \cdot 10^{10}$ kWh/year	See Base Case results in Task 4 (4.5, 4.5.10)

Complementary to Fraunhofer's bottom-up estimates above EuroStat data can be referenced for a plausibility check:

EuroStat provides data regarding energy consumption per industry sector, which allows estimating plausible ranges of electricity consumption related to machine tools (top-down approach). Data for 2008 and 2009 is provided in Table 1-15 with electricity consumption of 1.135 TWh in 2008 for the industry in EU-27, thereof 163 TWh for sectors machinery and transportation equipment, which are those, where metal working machine tools are used, and 28 TWh in sector wood and wood products, covering woodworking machinery. Machine tools in these sectors should consume significantly below 50% of the total energy consumption in these sectors (rather 10-30%), as a major share of electricity is used for thermal processes, infrastructure, material handling, surface treatments and coatings etc.

Table 1-15: Electrical Energy Consumption EU-27, 2008/09

Electrical energy (Final Energy Consumption in kWh)	2008	2009
Industry	$1{,}135 \cdot 10^{12}$	$9{,}81 \cdot 10^{11}$
Thereof sub-sectors:		
Machinery	*1,08* $\cdot 10^{11}$	*9,4* $\cdot 10^{10}$
Transport Equipment	*5,5* $\cdot 10^{10}$	*4,8* $\cdot 10^{10}$
Wood and Wood Products	*2,8* $\cdot 10^{10}$	*2,5* $\cdot 10^{10}$

Compared to these figures our own estimates are to be considered rather worst-case, but meet a plausible order of magnitude.

The 2011 study to revise the MEEuP methodology (now: MEErP)[50] split the total EU-27 energy consumption among the various consumers (top-down approach) and estimated the annual electricity consumption of "machine tools" with 120 TWh (without providing a distinct definition of their understanding of "machine tools"), which is at the upper range limit of our own screening.

1.1.5.1.2 Welding and Soldering Equipment

The 2007 Working Plan Study provides an environmental screening of welding and soldering equipment (named "Automatic and Welding Machines"), which is covered in this study by the definition of "machine tools", based on MEEuP[51].

The input parameters and the results of the assessment of the Working Plan study are as follows, including comments from a first screening of the product group by Fraunhofer:

Table 1-16: Working Plan Study Plausibility Check – Welding and Soldering Equipment[52]

Welding and Soldering Equipment (source: EPTA)		Screening by Fraunhofer
Estimated composition of Manufacture	Total weight 50 kg - average of 0,5kg to 200kg; steel, plastics, electronics, electrode, possibly gas (argon etc.)	Plausible for the majority of transportable units
Stock [tsd.]	6192,00	Stating a stock of several million units in the EU27 is a plausible order of magnitude, but covers largely transportable units Estimate[53]: • Welding / soldering equipment: 5 – 10 million
Estimated Power consumption [kWh/h]	25,00	Appropriate for larger automated units, but majority of transportable units are rather at 5 kW power consumption
Estimated use time per year [hours]	2120	Appropriate for larger welding machines, but the vast majority of

50 Kemna, R.: Methodology for Ecodesign of Energy-related Products, MEErP 2011, Methodology Report, Part 2: Environmental policies & data, 2011, p. 50

51 VHK VAN HOLSTEJIN EN KEMNA BV, *Methodology Study Eco-Design of Energy-using Products (MEEuP)*, 2005.

52 Note: The screening was primarily performed for categories deriving from group 28.4 "Manufacture of metal forming machinery and machine tools".

53 For detailed figures see Task 2

Welding and Soldering Equipment (source: EPTA)		Screening by Fraunhofer
Estimated Use Pattern	8h*265days	transportable units is used much less frequent, approximately 1-2 h per working day: 1-2 h/day; roughly 250-500 hours/year
Estimations energy consumption use for 1 year [kWh]	53000	1250-2500
Total energy [kWh]	$3{,}28 \cdot 10^{11}$	$6 – 25 \cdot 10^{9}$

Table 1-17: MEEuP results for “Automatic and Welding Equipment” (source: Working Plan study, EPTA)

Table . Summary Environmental Impacts EU-Stock 2005, AUTOMATIC AND WELDING MACHINES

main life cycle indicators	value	unit
Total Energy (GER)	3446	PJ
of which, electricity	328,2	TWh
Water (process)*	230	mln.m3
Waste, non-haz./ landfill*	4001	kton
Waste, hazardous/ incinerated*	79	kton
Emissions (Air)		
Greenhouse Gases in GWP100	150	mt CO2eq.
Acidifying agents (AP)	887	kt SO2eq.
Volatile Org. Compounds (VOC)	1	kt
Persistent Org. Pollutants (POP)	23	g i-Teq.
Heavy Metals (HM)	59	ton Ni eq.
PAHs	7	ton Ni eq.
Particulate Matter (PM, dust)	19	kt
Emissions (Water)		
Heavy Metals (HM)	22	ton Hg/20
Eutrophication (EP)	0	kt PO4

*=caution: low accuracy for production phase

Presumably the EPTA study overestimated the impact of welding equipment as the stock figures are plausible, but cover in their vast majority transportable units, which consume rather 5 than 25 kWh/h electricity when in operation, but being actually in operation only for 1-2 hours per working day.

This plausibility check indicates that the impact of welding equipment and the like had been rather overestimated by EPTA.

Note, that most of the welding and soldering equipment is included also in the overall sector electricity consumption for metal working as discussed on page 53.

1.1.5.1.3 Stone and Ceramics Working Machine Tools

The 2007 Working Plan Study provides an environmental screening of machines for treatment of stone, ceramics, concrete, referring to the related categories under

PRODCOM 28.49, but as EPTA stated a minor relevancy compared to other energy-using-products for these kind of equipment they were not subject to a MEEuP screening.

Table 1-18: Working Plan Study Plausibility Check – Stone and Ceramics Working Machine Tools[54]

Stone and Ceramics Working Machine Tools (source: EPTA)		Screening by Fraunhofer
Estimated composition of Manufacture	n.a.	Similarities to wood working machine tools expected: Metal / steel parts are dominating, 50 – 500 kg for typical units
Stock [tsd.]	n.a.	estimate[55]: • Stone and ceramics working machine tools: 0.5 - 1 million
Estimated Power consumption [kWh/h]	n.a.	rough assumption for typical power consumption: • Stone and ceramics working machine tools: 10 kW
Estimated use time per year [hours]	n.a.	assumptions: • Stone and ceramics working machine tools: 4 h/day, 1,000 hours/year
Estimated Use Pattern	n.a.	
Estimations energy consumption use for 1 year [kWh]	n.a.	• Stone and ceramics working machine tools: $1*10^4$ kWh/year
Total energy [kWh]	n.a.	Electricity: • Stone and ceramics working machine tools: $0,5\text{-}1*10^{10}$ kWh/year

1.1.5.1.4 Summary

Summarising the plausibility check of the data provided by the Working Plan Study, and referring to power consumption only, the following ranking of market segments regarding their environmental relevancy can be provided:

(1) Metal working machine tools (EU27 electricity consumption 75-110 TWh/year)

(2) Wood working machine tools (EU27 electricity consumption: 10-20 TWh/year)

54 Note: The screening was primarily performed for categories deriving from group 28.4 "Manufacture of metal forming machinery and machine tools".

55 For detailed figures see Task 2

(3) Welding and Soldering equipment (EU27 electricity consumption: 6-25 TWh/year)

(4) Stone and Ceramics Working Machine Tools (EU27 electricity consumption: 5-10 TWh/year)

Summarising the results of this screening it is evident, that the metal working machine tools are much more relevant in terms of energy consumption – same can be assumed regarding production related material consumption given stock estimates and typical weights per machine - than the other three types of machine tools. Given the uncertainty of the screening it can be concluded, that the impact of wood working machine tools, welding and soldering equipment, and stone and ceramics working machine tools is on an equal level.

1.1.5.2 Further assessments of metal working machine tools

VDW energy efficiency study

The requirement of a much diversified examination becomes evident under the inclusion of other studies dealing with the specific features of machine tools. In 2008, the **VDW** initiated a data acquisition concerning the energy efficiency of machine tools. In a non-representative survey, manufacturers from the German machine tool branch were questioned about several features of their products, such as specific weight, connection power, produced number of items, and power consumption.

As mentioned above, the survey lacks representativeness, but is a useful source to get an impression of the characteristics of machine tools. The following figures illustrate the results of the VDW survey.

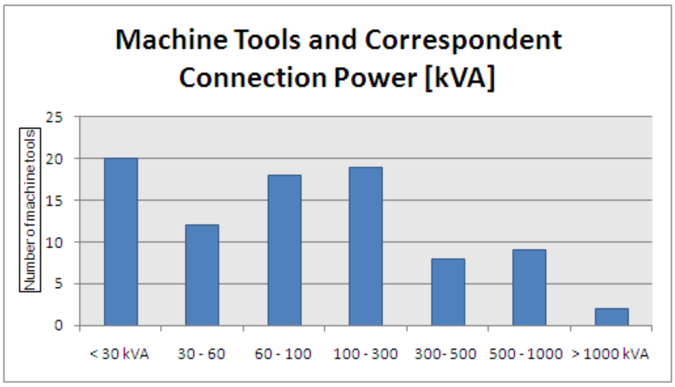

Figure 1-6: Connection Power of Various Machine Tools (VDW Survey)

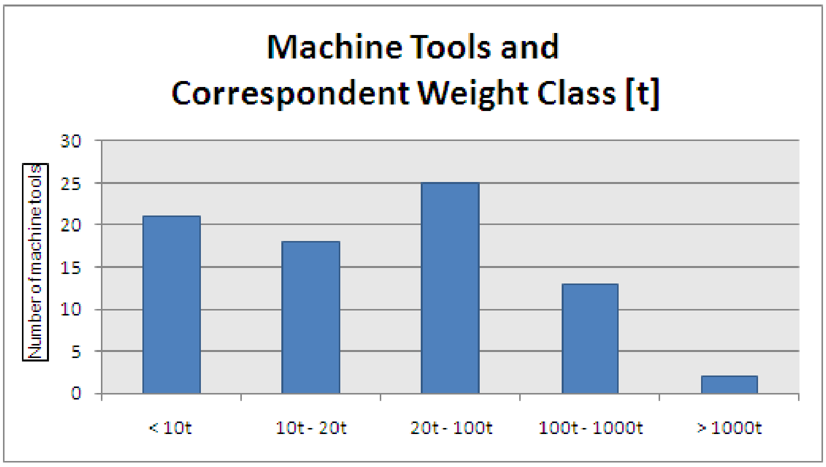

Figure 1-7: Weight of Various Machine Tools (VDW Survey)

Table 1-19: Key data deriving from the VDW survey

Machine Tools	Weight [t]	Produced Items [units]	Connection Power [kVA]
Mean	369,69	19,73	223,41
Sample Variance	3.737.687,54	1.025,98	160.430,44
Standard Mean Error	1.933,31	32,03	400,54

Figure 1-6 and Figure 1-7 illustrate the broad range of connection power and weight for different kinds of metal working machine tools which is supported by the statistical evaluation in Table 1-19. The heterogeneity of the parameters ‘weight’ and ‘connection power’ is expressed in the large deviations from the mean average value. It should be noted, that VDW represents the manufacturer of metal working machine tools, which in terms of connection power and weight are not comparable with wood working machine tools in their majority.

Key data derived from the evaluation of the survey are listed in Table 1-19. Compared with the screening by EPTA, however, we see that the mean for the weight is 369.69 tons, whereas EPTA calculates with an approximate value of 0.3 tons. Similar discrepancies appear regarding the Connection Power. EPTA states, that “the majority operates in the range of 30kW – 60kW, although there are machines of 250kW and 5kW”.[56] The VDW survey gives the impression that the majority of machine tools feature connection powers up to 300 kVA, besides the fact that the range between 30kW and 60kW is less representative.

56 EPTA LTD, ref 13, p. 258f.

The findings of these two studies and our own horizontal estimates already illustrate, that the product category machine tools cannot be analysed on such a meta level only, but that a distinction is required, addressing the specifics of the various sub-segments.

CECIMO life cycle assessments of machine tools

In preparation of a proposal for a Self-Regulatory Initiative (SRI) **CECIMO** contracted a Life Cycle Analysis[57] (LCA) of two typical types of metal-working machine tools (milling and turning, assessment of 9 individual machine tools) with a clear result that "the use phase dominates the environmental impact in all considered categories. In the use phase the most important influencing factor is the energy consumption." Results are depicted in Figure 1-8, based on the following settings: 100.000 hours productive operating with specific average energy consumption, consumption of 4.000 kg coolant lubricant and of 400 l hydraulic oil.

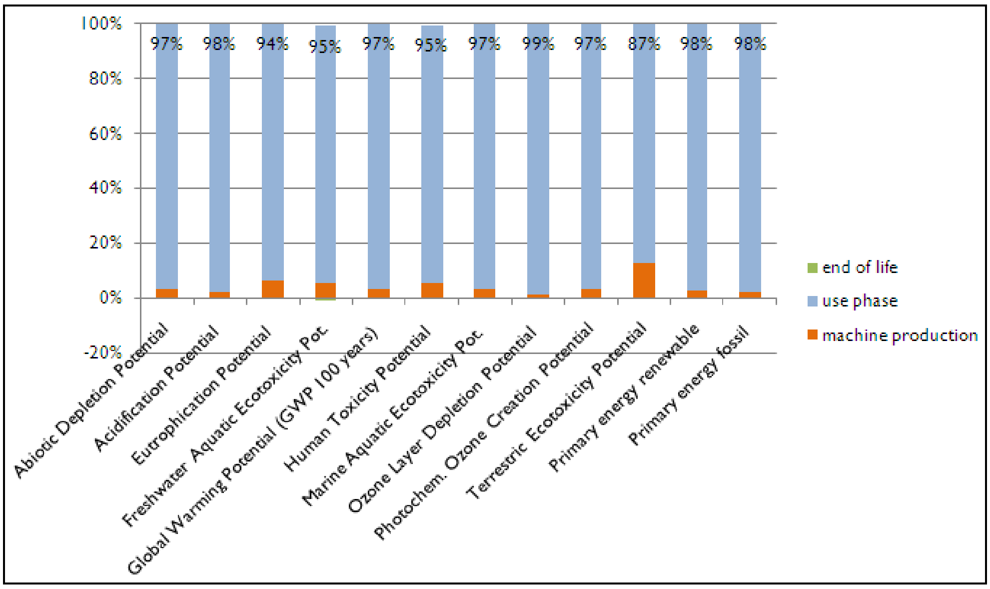

Figure 1-8: Average LCA results for machine tools split into production, use phase and end of life

The consumption of hydraulic oil, lubricant and electric energy of machine tools during the use phase is displayed in Figure 1-9. Electrical energy is dominating clearly, cooling lubricant and hydraulic oil being negligible according to these results.

57 CECIMO, *Concept Description for CECIMO's Self-Regulatory Initiative (SRI) for the Sector Specific Implementation of the Directive 2005/32/EC (EuP Directive)*, 2009.

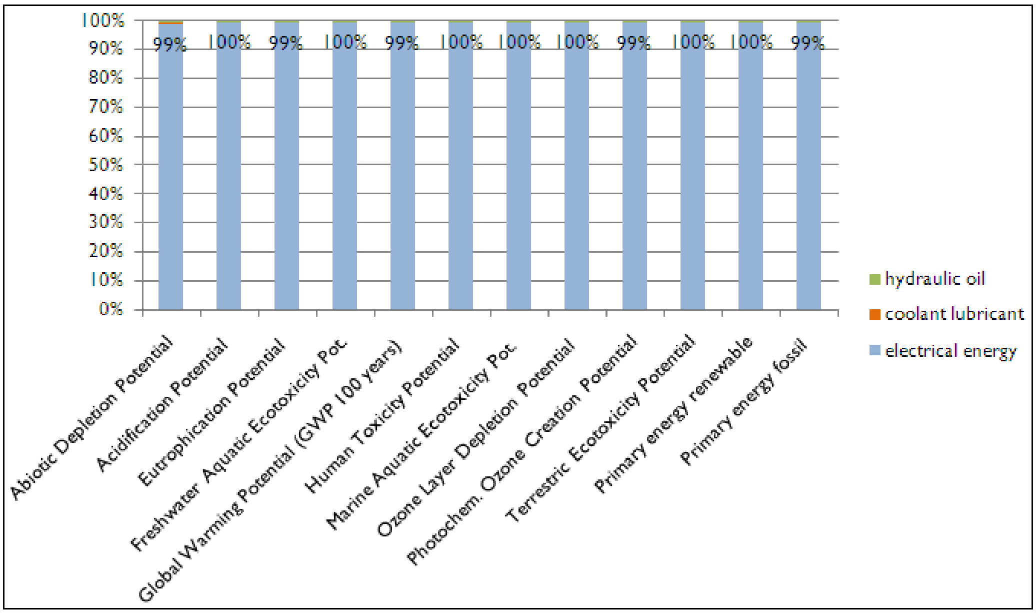

Figure 1-9: Average impact of consumables and energy of machine tools during use phase

The LCAs provided by CECIMO severe for a first orientation, further details are taken into account in the base case assessments in task 4.

Other research

Howard[58] states that Makino pushed efforts to make their machine tools as small and compact as possible and achieved a 40% size reduction for some of their vertical machining centres compared to previous generations. For other machine tools manufacturers similar trends have been observed.

The Minimum Quantity Lubrication (MQL) approach allows to eliminate large volumes of waste water, resulting in positive secondary environmental effects: MQL sprays also can be applied in a manner that eliminates mist, maintenance, and disposal operations associated with water-based cooling lubricants[59]. Clarens et al. published LCA results comparing four alternative systems for metal working fluids, showing clear improve-

58 SCIANNA, M., *Green Machine – Energy efficient, eco-friendly designs now mainstream in machine tools*, 2008.

59 ADLER, D. P. H, W, W.-S., MICHALEK, D. J., SUTHERLAND, J. W., *Examining the role of cutting fluids in machining and efforts to address associated environmental / health concerns,* 2006.

ment potentials when changing over to MQL[60] for some, but not all impact categories (see Figure 1-10). In particular life cycle energy consumption and GWP are increased.

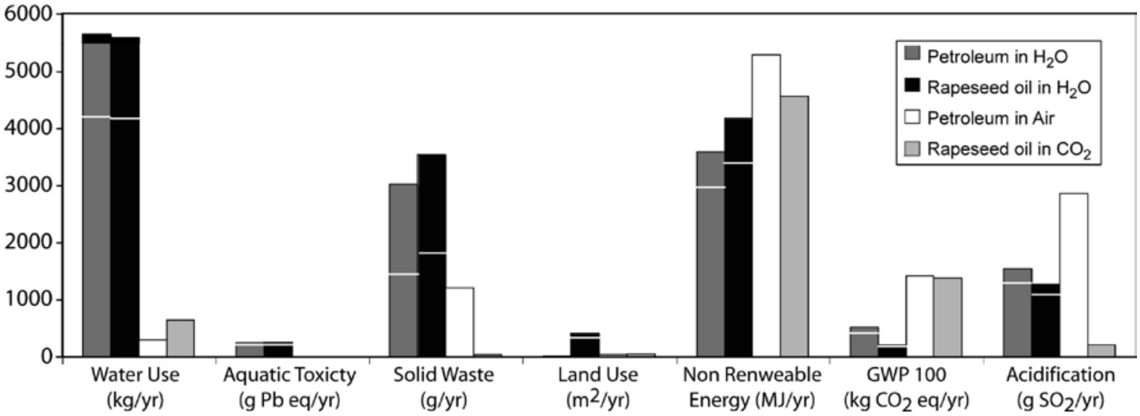

Figure 1-10: Life cycle burdens for the four metal working fluids systems based on expected application conditions

Based on different manufacturing scenarios, Abele et al.[61] assessed the overall energy consumption with special regard to losses due to idle periods, exemplary for a 5-axis machining centre. For a 3-shift operation series production, naturally, only 3% of the total energy use is accounted for the maintenance of the machine during downtime. However, compared to occasional manufacturing, the operational mode is significantly energy intensive, as depicted in Figure 1-11. Occasional manufacturing, on the other hand, is characterized by a share of 43% which are lost due to downtimes. In the latter case, as saving potentials are given in the field of appropriate energy modes during stand-by, energetic optimisation of single modules and the overall machinery can be applied for series production. In this regard, single modules need to be assessed in order to single out energy intensive devices, which are reliant on type of manufacturing, machinery, selection and arrangement of components, and machining task. According to the measurement performed by Abele et al., the hydraulic motor, the power train, and the low pressure cooling lubrication pump were identified holding the major share of energy usage, each of them providing different potential for improvement measures.

60 CLARENS, A.F., ZIMMERMAN, J. B., KEOLEIAN, G.A., HAYES, K.F., SKERLOS, S.J., *Comparison of Life Cycle Emissions and Energy Consumption for Environmentally Adapted Metalworking Fluid Systems*, 2008.

61 ABELE, E., DERVISOPOULOS, M., KUHRKE, B., *Bedeutung und Herausforderungen der Lebenszyklusanalyse am Beispiel Werkzeugmaschine,* 2009, 60.

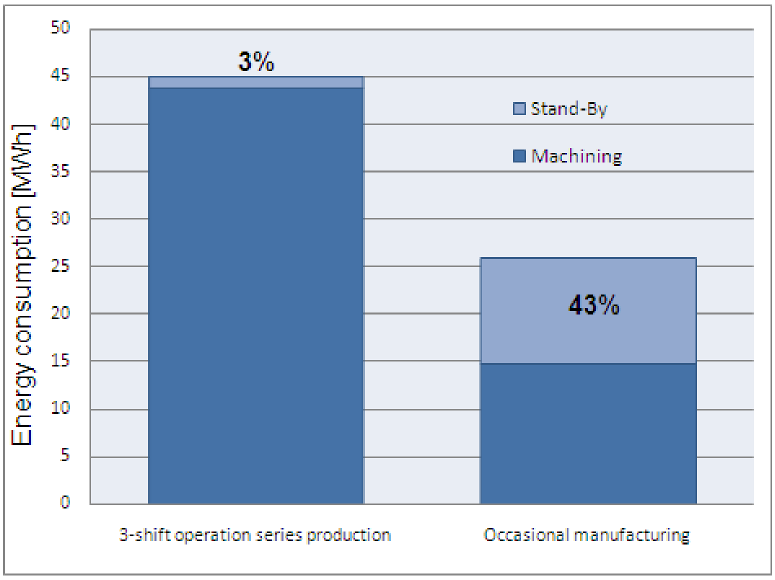

Figure 1-11: Energy consumption and idle losses of machine tools depending on different manufacturing scenarios. Figure adapted from Abele et al.[62]

Relevant power consumers of a machine tool are pumps, drives, chillers, power losses of transformers and power supplies. Figure 1-12 depicts the various consumers of electrical power in a cutting metal-working machining centre according to Pause.[63] Only 20% of the power consumption is directly related to the process as such, 80% is for auxiliary components of the machine tool.

62 Abele, E. et al.

63 PAUSE, B., *Energieeffizienz in der Werkzeugmaschinenentwicklung und im –Einsatz*, 2009.

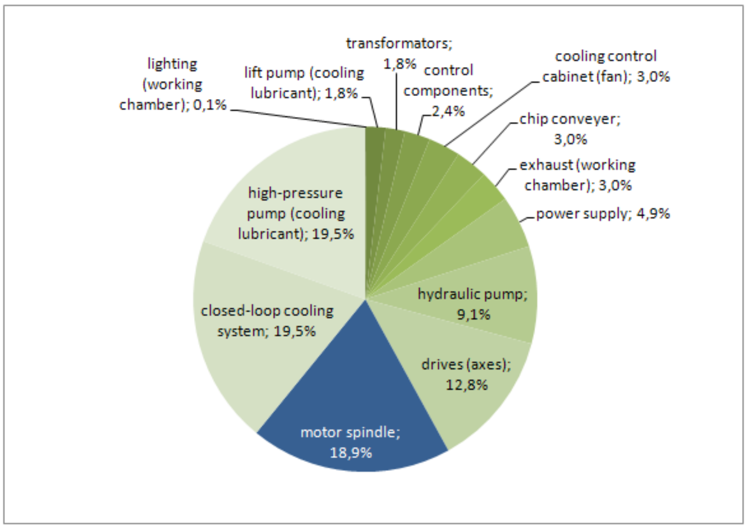

Figure 1-12: Electrical Power Consumption of Machine Tools – Shares of individual consumers

Similar figures are stated by Kuhrke,[64] referencing Volkswagen in Salzgitter (see Figure 1-13), where the grinding spindle consumes 21% of the overall power of the machine tool, and almost all of the remaining power consumption is related to pumps, either for coolants supply and removal or hydraulic oil.

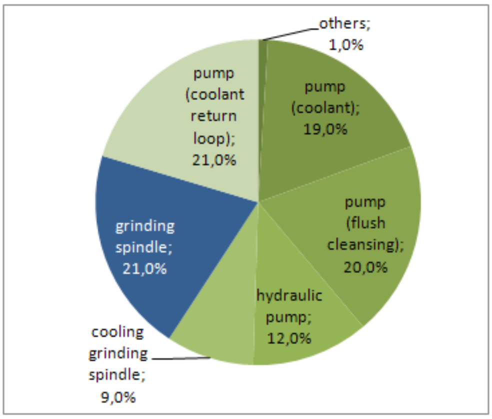

Figure 1-13: Electrical Power Consumption of a grinding machine at Volkswagen

Improvement potentials for a better energy efficiency of machine tools and reduction of lubricants and pressurized air consumption are manifold[65,66] to name only a few:

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64 KUHRKE, B., *Ansätze zur Optimierung und Bewertung des Energieverbrauchs von Werkzeugmaschinen*, METAV Trade Fair, 2010.

65 SCIANNA, M.

- optimal dimensioning of motors
- mass reduced slides
- energy-efficient motors
- reduction of warm-up phases (sensor based compensation)
- working chamber design for optimal chip removal (small size, sloped walls...)
- shorter process times through MQL
- implementation of standby modes and shut-off machine tools components in stand-by (cooling lubricants pumps, axes drives, chillers etc.)
- machine turn-off after a set idle time
- automatic lights off when working chamber doors closed
- closed-loop oil bath
- grease system replacing oil lubricants on guideway systems
- dry-cutting (increasing productivity in some cases)
- implementation of “smart” control technologies

In another assessment, Klocke et al.[67] published LCA data for a key component of a **milling machine**: a **tool changing unit** with a weight of 350 kg. Based on an assessment with the Eco-indicator 99 the power consumption in the use phase is confirmed to be the dominating environmental aspect (92,7% of Eco-points over the full life cycle), followed by raw materials production (3,7%) and transports (3,1%), disposal being negligible (0,6%).

As a stakeholder input Reis provided LCA results[68] for a **press-brake**, which indicates, that the production phase of the press-brake, contrary to other LCAs on metal working

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66 PAUSE, B.

67 KLOCKE, F.; LUNG, D.; NAU, B., *Umweltorientiertes Lebenszyklusmanagement - Bewertung ökologischer Einflüsse und Kostenbetrachtung im Lebenszyklus von Werkzeugmaschinen*, 2008.

68 Santos, J.P.; Oliveira, M.; Almeida, F.G.; Pereira, J.P.; Reis, A.: Improving the environmental performance of machine-tools: influence of technology and throughput on the electrical energy consumption of a press-brake, Journal of Cleaner Production, (2010), article in press

machine tools (see above) indeed could be relevant in terms of life cycle impacts. Results of their LCA study based on the Eco-Indicator 99 are provided in Figure 1-14. This study will be taken into consideration for the base case assessments in Task 4.

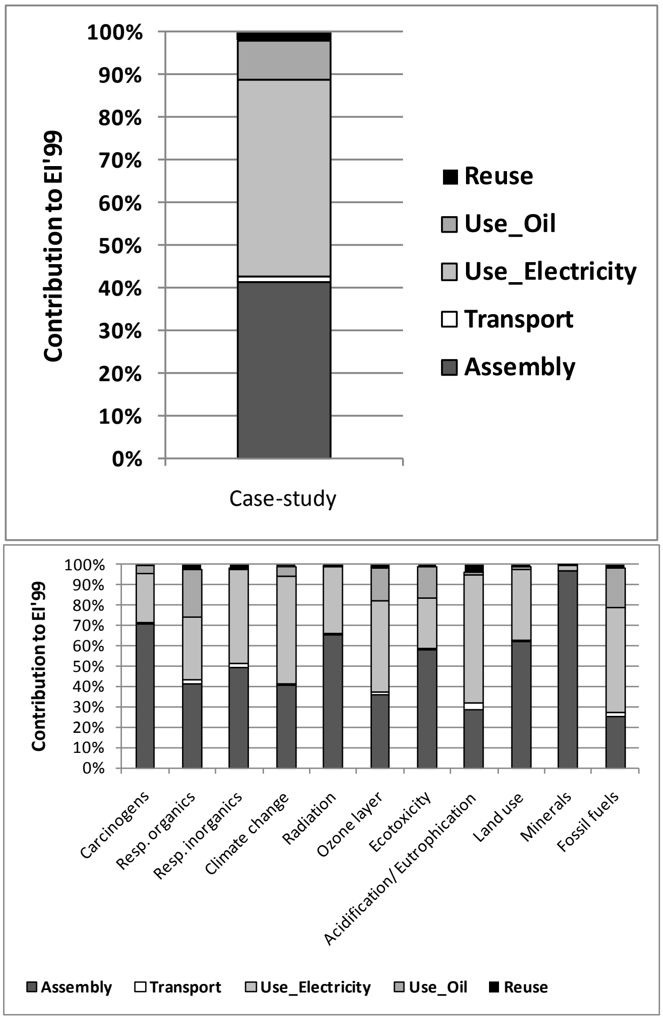

Figure 1-14: Environmental profile and relative contributions of life-cycle phases to the global environmental impact of a press-brake

1.1.5.3 Further assessments of Welding Equipment

Junnila[69] published a Life Cycle Assessment of a metal inert gas (MIG) welding equipment with a hybrid LCA approach. Besides the fact, that the equipment is modelled with a 10 years lifetime, no further details regarding the assumed use scenario

69 Junnila, S.: Life cycle management of energy-consuming products in companies using IO-LCA, International Journal of Life Cycle Assessment (2008), 13, p. 432-439

and specifications are disclosed. However, the results presented in Figure 1-15 indicate, that the sourcing (most likely material acquisition for production of the welding equipment) is relevant for several impact categories, frequently even dominating the use phase. As a consequence for welding equipment the focus of following analyses should not be solely on power consumption in the use phase.

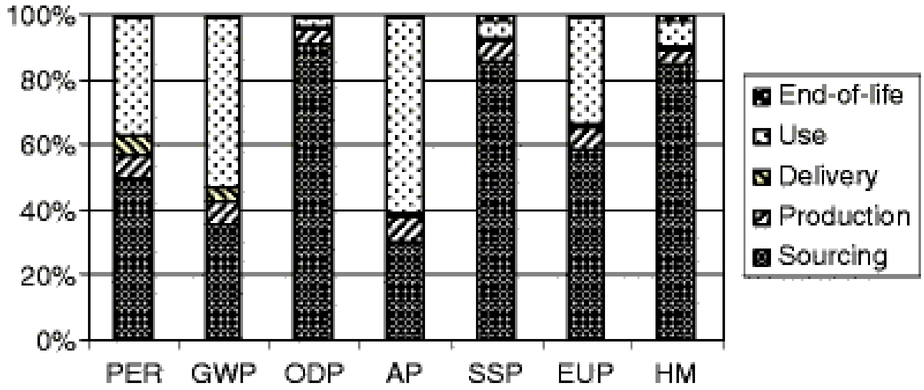

Figure 1-15: Environmental contribution of the main life cycle phases of a MIG welding equipment

1.1.5.4 Environmental Screening of Plastics and rubber machinery

Plastics and rubber processing machinery represents an important market. As the dominating moulding and extrusion processes are primary shaping processes most of the plastics processing machinery do not meet the condition of processing a workpiece of determined shape. Consequently this machinery does not fall under the core definition of a “machine tool”, but might be considered as “related machinery”. Only if plastics and rubber processing machinery is of significant market relevance and environmental improvement potential, and if the modules used in this type of machinery are comparable to typical machine tools, only then plastics and rubber processing machinery will be considered further.

Market Relevance

Although there is a PRODCOM code **28.49.12: Machine tools for working wood, cork, bone, hard rubber, hard plastics or similar hard materials; electroplating machinery** according to EUROMAP/VDMA no rubber or plastics processing machinery is reported under this code. Instead, the vast majority of plastics and rubber processing machinery is covered in market statistics under **28.96: Manufacture of plastics and rubber machinery**.

For 2009 EuroStat states an EU-27 production value of 4.65 Billion Euros[70] and in terms of units 133,057 produced machines. A plausibility check of this data by Fraunhofer, which excludes unit figures (obvious over-estimates, likely reporting of low-value consumer products, and obvious misallocation of presumably parts and the like; for details of the plausibility checks see criteria explained in task 2 report), results in lower numbers: **3.85 Billion Euros production volume** and **61,000 produced machines** (see Table 1-20).

Table 1-20: Plastics and rubber machinery - Production Volume 2009 and Plausibility Check

PRODCOM Code 2896..		Volume EU27 according to EuroStat	FRAUNHOFER Plausibility Check	Re-calculation rule	re-calculated EU27 Volume	re-calculated Value in THOUSANDS	re-calculated unit value
1010	Injection-moulding machines for working rubber or plastics or for manufacturing rubber or plastic products	31,200	non-plausible volume for HU at low market share	GER, I, F, ES	6,373	503.440,69	79.002
1030	Extruders for working rubber or plastics, or for manufacturing rubber or plastic products	5,362	market share GER, I, A: 95%, unit value plausible for all relevant countries	no recalculation	5,362	1.020.686,71	190.356
1040	Blow-moulding machines for working rubber or plastics or for manufacturing rubber or plastic products	1,992	relevant market share is confidential, but rest and EU27 unit value plausible	no recalculation	1,992	450.106,17	225.957
1050	Vacuum-moulding machines and other thermoforming machines for working rubber or plastics or for manufacturing rubber or plastic products	4,697	UK relevant volume, but at 3000 Euro unit value	EU27-UK	2,803	159.095,70	56.759
1060	Machinery for moulding or retreading pneumatic tyres...	2,192	most of the market not substantiated with volume; but EU27 unit value is plausible	no recalculation	2,192	228.585,85	104.282
1073	Other presses for moulding or forming rubber or plastics, etc, n.e.c.	1,228	ES at low unit value of 8.500 Euro, GER and I at nearly 90% market share	GER, I	0,992	145.196,96	146.368
1075	Machinery for moulding or forming rubber or plastics, etc, n.e.c.	8,931	huge differences regarding unit values, even among countries with large market share (13.000-290.000 Euro); PL at unit value 1.700 Euro	EU27-PL	8,247	255.810,80	31.019
1082	Machines for processing reactive resins	1,404	I with significant market share in terms of units at 2.700 Euro unit value; no data disclosed from other countries; calculation not verifiable	EU27-I	0,480	106.095,66	221.033
1084	Machines for the manufacture of foam products (excluding machines for processing reactive resins)	0,389	GER 95% market share, others not disclosed (at likely rather low unit value)	GER	0,317	128.627,73	405.766

70 all of 28.96 except parts

1091	Size reduction equipment for working rubber or plastics	5,068	I at unit value 2.900 Euro, others in the range 6.000-25.000 Euro; small scale equipment covered	EU27-I	4,625	73.707,01	15.937
1093	Mixers, kneaders and agitators, for preparing rubber or plastics	3,371	GER, I 98% of all units	GER, I	3,291	102.372,06	31.107
1095	Cutting, splitting and peeling machines for working rubber or plastics or for the manufacture of products from these materials	4,182	GER, ES, I 90% market share at unit values 24.000 - 40.000 Euro	GER, ES, I	3,413	127.519,41	37.363
1097	Machinery for working rubber or plastics or for the manufacture of products from these materials, n.e.c.	63,041	GER 50% of units, but no value disclosed; EU27 total value rounded; only countries with disclosed unit values > 15.000 Euro taken into account, but uncertainty regarding GER figures is a major shortcoming	DK, I, A, P, FIN, UK	20,776	544.608,81	26.213

Of these 61,000 produced machines roughly 40,000 are of a unit value below 50,000 Euro, the remaining 20,000 units start at roughly 50,000 Euros each, but comprise also categories, such as extruders and blow-moulding machines with average unit values in the 200,000 Euro range.

Import to the EU-27 and export from any EU-27 country to outside EU-27 in terms of monetary value according to figures provided by VDMA for the years 2007-2009 is summarised in Table 1-21.

Table 1-21: Plastics and rubber machinery – EU-27 import and export (billion Euros)

	2007	**2008**	**2009**
Export from EU-27 to other countries	5.47	5.26	3.78
Imports to EU-27 from other countries	1.13	1.12	0.76
for comparison:			
Production (EuroStat, EU-27)	6.98	7.74	4.65
Production (plausibility checked)	5.68	6.07	3.85
Production (plausibility checked)	88,000 units	91,500 units	61,000 units

There is an obvious mismatch between export figures and production figures, as production is only slightly higher than exports, whereas the EU-27 export even neglects the significant EU-27 internal trade between member countries. Even with an assumed significant trade of used equipment either export figures seem to be too high or production too low.

However, taking into account the production figures of PRODCOM (plausibility checked), and the fact, that a major share of the EU-27 production is exported and a comparing smaller number is imported out of roughly 80,000 units manufactured per year (but notice year-to-year fluctuations), the newly installed stock might be in the range of 40-50,000 units per year. A 2005 survey among plastics processing companies reported an average age of the relevant machinery of 9 years, ranging from 6 years in Germany to 13 years in UK, which illustrates the huge spread even among European countries[71]. Injection moulding, extrusion and compounding machines are in average 6 to 8 years old, transfer moulding machinery and presses are nearly 14 years old in average. Logically, lifetime is longer than average age of any operating machinery: Given a lifetime of 10-20 years this means a range of **400,000 – 1 million units of installed stock of plastics and rubber machinery** in EU-27, thereof 2/3 smaller machinery, e.g. for prototype or laboratory use and the like, and 1/3 for large-scale industrial use. For comparison: Petri[72] states a figure of 55,500 injection moulding machines – being one of the most relevant market segments - installed in Germany based on 2005 sources, which confirms the plausibility of having a few 100,000 industrial plastics processing machines installed in the EU-27.

Use patterns

Roughly 2/3 of the plastics processing enterprises work **24 hours 5 days a week**. Another 15% even 24 hours 7 days a week. Only 20% of the companies work in one or two shifts[73]. Utilization according to the same survey is typically above 60%, but it can be assumed, that this figure is subject to fluctuations with economic cycles. Highest utilization rates are those of extrusion processes, compared to the batch processes of moulding.

As of 2005 28% of the plastics processing enterprises monitored and reviewed the energy usage of each of their machines[74], and a significant share of companies underwent an energy audit or contracted an energy consultant. However, the conclusion is, that energy consumption is an important topic for the plastics processing industry, but

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[71] Fraunhofer ICT: Energieverbrauch und Einsparmöglichkeiten in der Kunststoffverarbeitung – Europäischer Vergleich zum Energieverbrauch und Einsatz bestmöglicher Technologien, November 2005, p. 9

[72] Petri, E.: Leistungselektronik, Kosten und Energie sparen in der Kunststoffverarbeitung, 30 November 2009, Ansbach

[73] Fraunhofer ICT: Energieverbrauch und Einsparmöglichkeiten in der Kunststoffverarbeitung – Europäischer Vergleich zum Energieverbrauch und Einsatz bestmöglicher Technologien, November 2005, p. 11

[74] Fraunhofer ICT: Energieverbrauch und Einsparmöglichkeiten in der Kunststoffverarbeitung – Europäischer Vergleich zum Energieverbrauch und Einsatz bestmöglicher Technologien, November 2005, p. 9

as of 2005 there is still room for improvement regarding transparency of energy consumption and attention paid to this aspect.

Environmental Relevance

Based on a stated average energy consumption of plastics processing of 1.85 kWh/kg and a total estimated consumption of 40 million tonnes plastics in 2005 Fraunhofer ICT[75] estimated a total power consumption of plastics processing of **74 TWh** per year in the EU. Petri[76] states a figure of 24 TWh power consumption for injection moulding in Germany, which looks rather high in comparison to the 74 TWh for plastics processing in EU-27, leading to the assumption that the total power consumption might be even higher.

This is only a rough estimation as the specific energy consumption depends inter alia on the actual type of plastics processed and the type of process: According to the above 2005 survey the site specific energy consumption ranges from below 1 kWh/kg for compounding and fibre extrusion to 3 kWh/kg for injection moulding and compression moulding and 6 kWh/kg for rotational moulding and thermoforming[77]. The average site specific energy consumption was stated with 2.87 kWh/kg, which makes sense in relation to the stated machine specific energy consumption of 1.85 kWh/kg.

What distinguishes plastics processing from e.g. metal working cutting and forming processes is the fact, that the melting of plastics granulates inevitably needs an input of heat to the process. Physically, the melting heat is a fixed value which is not subject to any improvement potentials. However, excessive heat and heat losses could be subject to improvement options.

Fraunhofer ICT stated as a trend, that the site specific energy consumption is lower in newer facilities with newer machines, but could not state with certainty, whether this is related to the newer, more energy efficient buildings or whether machines became more energy efficient - or both.

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[75] Fraunhofer ICT: Energieverbrauch und Einsparmöglichkeiten in der Kunststoffverarbeitung – Europäischer Vergleich zum Energieverbrauch und Einsatz bestmöglicher Technologien, November 2005, p. 2 / Prestudy Report EuPlastVoltage January 2010, p. 16

[76] Petri, E.: Leistungselektronik, Kosten und Energie sparen in der Kunststoffverarbeitung, 30 November 2009, Ansbach

[77] Note: the *site* specific energy consumption is higher than the *machine* specific energy consumption, as it includes also the site infrastructure, but as it was to possible in the frame of the cited survey to get hold of machine specific data, only site specific data was asked for

Power consumption of machinery in the plastics processing industry is dominated by[78]:

- Motors and drives with a minimum of 0.25 kWh/kg polymer for the drive motor of any machine, that melts plastics
- Process heating, including pre-drying of polymers
- Process cooling (water, air, chillers), to remove all energy that went into the melting process, avoiding any negative impact on product quality; indicatively a minimum for cooling is 0.25 kWh/kg polymer processed

Under optimal conditions the power consumption values could be even lower: Gehring[79] states as a good value of **0.35 kWh/kg** for injection moulding processes under the following conditions: Polypropylene, large machine, high throughput, properly maintained, hydraulics with variable speed drive.

Just as with other machines it has to be kept in mind that power consumption of a plastics processing machine in particular in relation to the output depends on the capacity utilization: Pamminger et al.[80] analyzed for an Austrian plastics processing company the electricity consumption. For a given machine at high utilization ratio of 17 kg/h parts output, the specific consumption is 5 kWh/kg. When utilization ratio is at 5 kg/h the specific consumption rises to 12.5 kWh/kg (Figure 1-16).

78 RECIPE: Low Energy Plastics Processing – European Best Practice Guide, October 2006, p. 5-6

79 Gehring, A.: Energieeffizienz in der Kunststoffverarbeitung – Potentiale identifizieren und nutzen, Kosten und Energie sparen in der Kunststoffverarbeitung, 30 November 2009, Ansbach

80 Pamminger, R.; Wimmer, W.; Winkler, R.: Entwicklung von Kriterien zur Kommunikation der Energieeffizienz von Kunststoff verarbeitenden Maschinen, 5/2010 p. 58

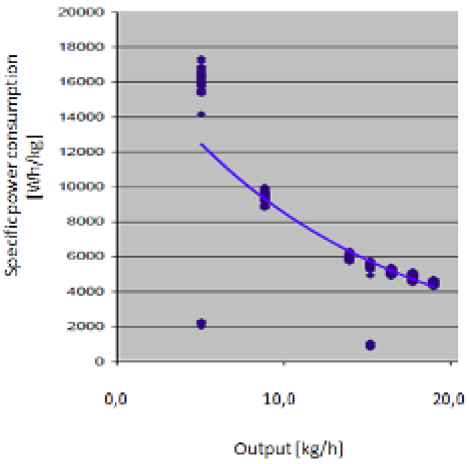

Figure 1-16: Specific energy consumption of an injection moulding machine

Improvement Potential

Based on the findings regarding the power consumption per output correlation Pamminger et al. conclude, that attention should be paid to

- eliminating fixed power consumers.

The RECIPE project identified the following general measures to reduce energy consumption in plastics processing[81]. Regarding the design of the machinery key aspects are:

- appropriate motor dimension / efficiency
- motors with constant or variable speed drive.
- short lines between vacuum pumps/compressors and consumers. Setting the correct pressure and switching off when not needed.

Users have to consider, if:

- motors and machines running in standby
- equipment running when production machines are not in use
- heat insulation is installed

81 RECIPE: Low Energy Plastics Processing – European Best Practice Guide, October 2006, p. 7

- chillers settings are correct in relation to working temperature and switch off mode
- controlling and reducing leakages in steam, air or water lines

Gehring[82] states an energy savings potential in plastics processing of "not uncommonly 30%".

A 2010 study by Fraunhofer ICT and Fraunhofer ISI[83] calculated three scenarios to demonstrate energy consumption and reduction potential in the plastics processing industry:

- Business-as-usual ("frozen scenario"): development without energy saving measures
- Reference scenario: reduction of energy usage because of increasing fuel costs, production volume and CO_2 costs. Saving options are realized driven by market demands.
- Voluntary agreement scenario: A higher level of diffusion of improvement options is anticipated, due to a commitment by industry, but no indication is given in the study, how such a voluntary agreement could look like, what are the quantified targets and how market surveillance might work, therefore this is a highly abstract scenario.

These scenarios are set up for injection moulding, extrusion and blow moulding as outlined below.

Injection Moulding

The energy consumption of injection moulding machines in particular depends on[84]:

- clamping force, design, size and complexity of the machine module
- use of hot runners, hydraulic cores or inserts

82 Gehring, A.: Energieeffizienz in der Kunststoffverarbeitung – Potentiale identifizieren und nutzen, Kosten und Energie sparen in der Kunststoffverarbeitung, 30 November 2009, Ansbach

83 EuPlastVoltage: Procedures and Targets, Deliverable 3.1, 3.2 , June 2010

84 RECIPE: Low Energy Plastics Processing – European Best Practice Guide, October 2006, p. 18

- ancillary equipment such as dehumidifiers, dryers and mould heaters
- type of plastic material used as some materials have a higher melt temperature, e.g. to melt polyolefins requires 0,2 kWh/kg, polyaromatics and some nylons require 0,4 kWh/kg[85]
- cycle time dictates the length of time the pump or electric motor is running during injection moulding process

80% of heating energy is dissipated by the cooling system. The other 20% of excessive energy are related to the plastification unit and are dissipated by radiation and convection.

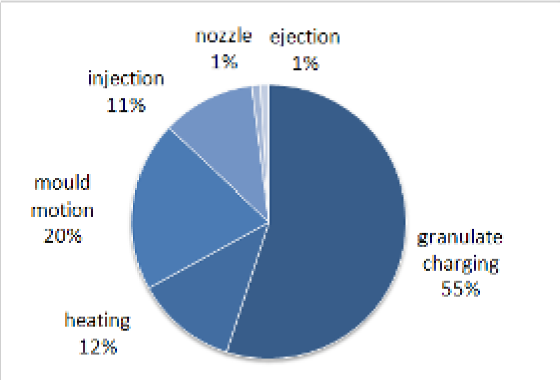

Figure 1-17: Average split of energy consumption of a “standard” injection moulding process

Brettnich[86] states an average split of the power consumption of injection moulding machine as shown in Figure 1-17: Motor and drives for granulate charging are dominating by far, followed by the drive system for mould motion and heating.

Wimmer et al. analysed in detail an exemplary middle size hydraulic injection moulding machine[87]. The energy balance per module is shown in the following table. Power consumption of motors and heating[88] are dominating. Energy, i.e. heat, is basically

[85] RECIPE: Low Energy Plastics Processing – European Best Practice Guide, October 2006, p. 8

[86] Brettnich, T.: Energieeffiziente Spritzgießmaschinen, Kosten und Energie sparen in der Kunststoffverarbeitung, 30 November 2009, Ansbach

[87] Wimmer, W.; Pamminger, R.; Winkler, R.E.: Energiedienstleistung zur Steigerung der Energieeffizienz von Spritzgießmaschinen im Kunststoffbereich 55/2009 p. 11, 16, 17, 28

[88] higher share than stated by Brettnich above

removed from the process with the cooling cycle connected to the mould and the hydraulic oil.

Table 1-22: Energy consumption of an injection moulding machine for standard applications

INPUT	Average (in kW)	**OUTPUT**	Average (in kW)
Motor supply	12,5	Hydraulic oil	8,5
Heating	7	Moulding cooling	9,9
Utilities and peripherals	3,5	Convection loss (calculated)	4,6

Wimmer et al point out that it is technically very difficult to recover the energy losses resulting from convection and radiation: An additional housing of the plastification unit might allow a recovery of convection heat to be transferred to pre-heat the plastics granulate before it enters the plastification unit.[89] However, this option would have a direct impact on the injection process. Heat transferred to the cooling water or hydraulic oil could be used, but according to Wimmer et al. externally to the injection moulding machine only and consequently this is not an option for a machine-centric ecodesign measure.

Comparing hydraulic, electric and hybrid machines for injection moulding, the RECIPE European Best Practice Guide states[90],[91]:

- "**Hydraulic** drives normally require continuous operation with minimum start-ups and shut downs making it difficult to improve energy savings. Machine control is vulnerable to hydraulic fluid temperature. Hydraulic system flow and pressure requirements vary throughout the cycle and in many cases excess fluid that is not required by the process is throttled back to the reservoir, wasting motor energy and producing additional thermal load on the cooling system." However, the reference to "many cases" indicates, that this is an improvement option, with which improved hydraulic systems might cope.

89 Wimmer, W.; Pamminger, R.; Winkler, R.E.: Energiedienstleistung zur Steigerung der Energieeffizienz von Spritzgießmaschinen im Kunststoffbereich 55/2009 p.7

90 RECIPE: Low Energy Plastics Processing – European Best Practice Guide, October 2006, p. 20

91 EuPlastVoltage: Procedures and Targets, Deliverable 3.1, 3.2 , June 2010, p. 12, but the wording is exactly the same as in the RECIPE Best Practice Guide. Obviously no technology update since 2006 is taken into account by the study authors

- "**All-electric** machines have the potential to reduce the energy usage in injection moulding by between 30 and 60% depending on the mould and machine used." This improvement potential obviously refers to an assumed 30 to 60% improvement compared to a hydraulic injection moulding machine. "All-electric machines do not require a hydraulic system as the power requirement is provided by the direct electrical drive. All-electric machines eliminate the need for the cooling of hydraulic oils. All-electric machines have lower power consumption at start up leading to lower maximum demand requirements."
- "**Hybrid** machines use both, servomotors and hydraulic pumps. Common configuration is using the hydraulic pump for clamping and the servomotors for the screw movements. Hybrid machines are generally lower in cost than the all-electric machines, however, they are not as energy efficient or as quiet."

Consequently, the EuPlastVoltage study[92] identifies an energy savings potential of **30,000 - 40,000 TJ** for 2020 when replacing hydraulic by electrical machines.

For Germany 2005 data and machine tests indicate that the total energy consumption of injection moulding machines is in the range of 24 TWh and roughly 12 TWh could be saved when shifting from hydraulic systems to all-electric systems[93]. However, a stated savings potential of 50% for drives, despite claiming to be based on real measured values, is in conflict with the fact, that the heating of the plastification unit usually is a major energy consumer, not only the hydraulic system.

Both, the EuPlastVoltage study and the data for Germany neglect the inherent improvement potential of hydraulic systems achievable with advanced state-of-the-art systems[94]. Hence, as of the technical status of 2010 the only improvement option might not be the drastic technological shift to all-electric systems, but also the optimal design of a hydraulic system, which could result in an overall low power consumption per kg plastics processed[95].

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[92] EuPlastVoltage: Procedures and Targets, Deliverable 3.1, 3.2 , June 2010, p. 32

[93] Petri, E.: Leistungselektronik, Kosten und Energie sparen in der Kunststoffverarbeitung, 30 November 2009, Ansbach

[94] The statement of 50% savings potential actually is at least partly based on sources as of 1999, i.e. Wortberg, J.; Michels, R.; Neumann, M.: Energieeinsparpotentiale in der kunststoffverarbeitenden Industrie, 1999

[95] See p. 10

Barrel insulation jackets[96,97,98] are an option to reflect radial emitted heat back into the plastification unit. The energy saving of heating elements with this approach can be in the dimension of 40-50%. Advantages can be shorter start up times, reduction of heat losses and operation cost.

Taylor and Aochi[99] states **induction heating** (instead of conventional heating-band heaters) as an option for a more energy saving design of plastification barrels for moulding machines. Depending on the type of plastics processed an average of 58.2% of the heating energy for the barrel could be saved (Figure 1-18) or 10% of the energy consumption of the whole injection moulding machine.

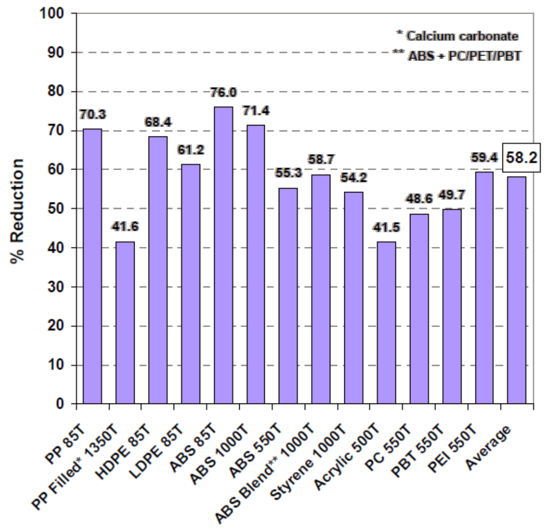

Figure 1-18: Reduction in barrel heating energy through induction heating (Taylor 2008)

Conformal Cooling is stated as a major measure to optimize the cooling process of the mould and the moulded part[100]: Most time of a cycle is needed when molten plastic

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[96] RECIPE: Low Energy Plastics Processing – European Best Practice Guide, October 2006, p. 20

[97] EuPlastVoltage: Procedures and Targets, Deliverable 3.1, 3.2, June 2010, p. 11

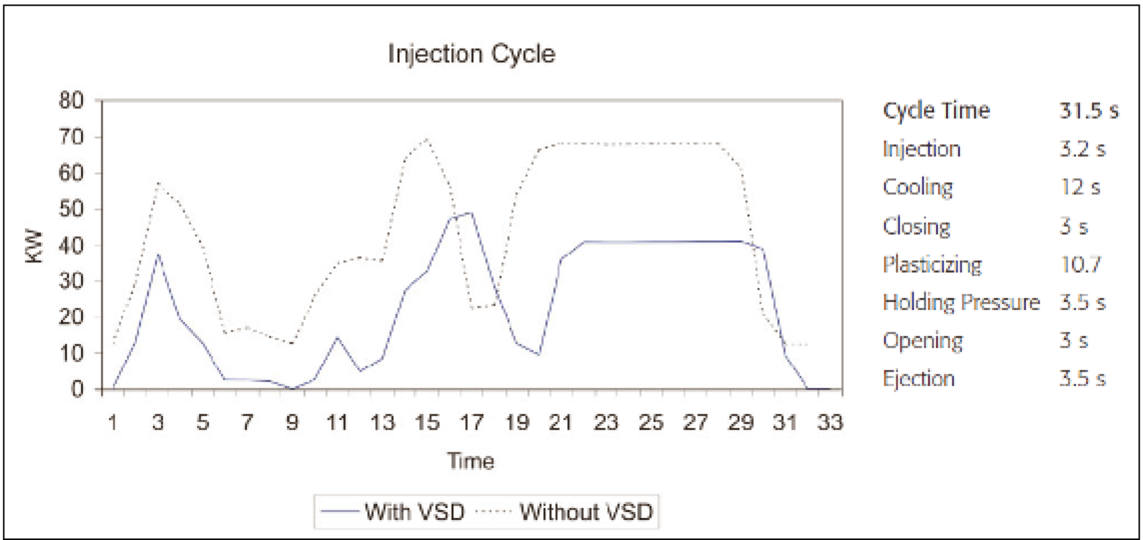
[98] Wimmer, W.; Pamminger, R.; Winkler, R.E.: Energiedienstleistung zur Steigerung der Energieeffizienz von Spritzgießmaschinen im Kunststoffbereich 55/2009, p.10

[99] Taylor, B.F.; Aochi, Y.: Induction Barrel Heating on Production Molding Machines – Quantifying Energy Savings & Understanding Influencing Factors, 2008, http://www.xaloy.com/pdf/induction_japan_techarticle.pdf

[100] RECIPE: Low Energy Plastics Processing – European Best Practice Guide, October 2006, p. 21

has to chill in the mould before ejecting. The traditional method for cooling moulds is to run water through straight shapes in the mould. As a result there is an irregular cooling of the mould. This causes longer cycle time, as a result of hot and cold spots in the mould. To reduce cycle time and disparities of temperature in the mould, the straight shapes can be changed to conformal shapes. Therefore the cooling channels should have the design of the part cavity. The consequence is a reduction of cooling time and a similar temperature in the mould. This method is reported to improve energy savings by 20-50%, but is related in a stricter sense to the design of the mould, not the injection moulding machine.

Typically injection moulding machines are driven by hydraulic pumps. The efficiency of hydraulic pumps declines, when the maximum oil flow is not needed. Oil is bypassed back to the reservoir. This can be avoided by using a **variable speed drive for the hydraulic pump**. Consequence is a lower oil temperature and less cooling. In addition the motor and cooling parts needs up to 50% less energy[101]. Durability increases, because wear and tear on the motor and related components are reduced. The reported savings potential of 50% for a hydraulic injection moulding machine actually is in contradiction with the statement of the same report as cited above, that energy savings in hydraulic systems for injection moulding can hardly be realized. Taken from the RECIPE Best Practice Guide Figure 1-19 depicts the comparison of an injection moulding machine with hydraulic pump with and without a Variable Speed Drive (VSD). The average power consumption of the machine decreases from 41 to 21 W.



101 RECIPE: Low Energy Plastics Processing – European Best Practice Guide, October 2006, p. 22

Figure 1-19: Comparative injection cycle with and without variable speed drive

Total savings for the three scenarios developed in the EuPlastVoltage project[102] are summarised in Table 1-23.

Table 1-23: Scenarios for injection moulding (EU energy consumption)

Scenario	2007	2020
Frozen, i.e. Business-as-usual (in TJ)	93,000	114,000
Reference (in TJ)	82,000	60,000
Voluntary agreement (in TJ)	82,000	45,000

In the case of business-as-usual, the energy consumption for injection moulding growth to 114,000 TJ in 2020. A more likely development driven by a consideration of energy costs results in a decreased power consumption from 82,000 TJ down to 60,000 TJ and in case of a more stringent implementation of improvement potentials in 45,000 TJ for the voluntary agreement scenario for the year 2020[103]. Contrary to this huge improvement potential Wimmer et al. [104] state, that in the past 20 years, injection moulding machines where improved regarding energy efficiency. Based on the findings in a typical Austrian plastics processing company, a comparison of injection moulding machines of different ages and with drive systems typical for the year of construction was calculated, showing an improvement of roughly 70% for a machine built in 2005 compared to a similar one with construction year 1983. According to Wimmer et al. European manufacturers develop and sale state-of-the-art machinery – with respect to the drive technology in particular. Given this fact the savings potential on the product level is considered rather minor by Wimmer et al., and further energy savings need to tackle systems aspects instead, i.e. machine external improvements, which are not in the scope of product related ecodesign measures.

Extrusion

The main energy consumers in the extrusion processes are motors, drives, heaters and cooling systems, in particular[105]:

102 EuPlastVoltage: Procedures and Targets, Deliverable 3.1, 3.2, June 2010, p. 31-33

103 For details of the calculated scenarios see the EuPlastVoltage report

104 Wimmer, W.; Pamminger, R.; Winkler, R.E.: Energiedienstleistung zur Steigerung der Energieeffizienz von Spritzgießmaschinen im Kunststoffbereich 55/2009 p. 12, 35

105 RECIPE: Low Energy Plastics Processing – European Best Practice Guide, October 2006, p. 26-28

- Cooling water for refrigeration of the extruder feeding zone
- Heating of the die
- Heating/cooling of the nip rollers
- Compressed air (necessary for blown film extrusion)
- Vacuum supply
- Haul off systems (profile extrusion)
- Cooling the products

Energy losses are related to sub-optimal extruder screw design, drive system efficiency (electrical motors, gears, power electronics, pumps, throttle valves, hydraulic pipes), friction (guides, bearings, sealings), heat losses at non-insulated surfaces[106].

Improvement options in their majority are related to adapted operation patterns, such as optimized and controlled water amount and temperature for cooling, setting the die temperature at the lowest possible level without hampering the process result, and optimising the water circulation system for cooling nip rollers. The machinery design could address these potentials by providing appropriate measurement and control features. Improvement options directly relevant for machinery components are

- motors and other components should be sized to match extruder capacity (avoid oversized and thus inefficient components),
- optimized compressed air supply for blown film extrusion and vacuum supply for profile extrusion.

Insulation of the barrel is not in every case possible, but in average 5% energy can be saved. Also insulation of the melt filtering system can reduce energy consumption. With this measure savings in the range of 700 TJ may be possible[107].

Total savings for the scenarios calculated by the EuPlastVoltage project are summarised in Table 1-24 for extrusion[108]: The more ambitious “voluntary agreement” scenar-

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106 Gehring, A.: Energieeffizienz in der Kunststoffverarbeitung – Potentiale identifizieren und nutzen, Kosten und Energie sparen in der Kunststoffverarbeitung, 30 November 2009, Ansbach

107 EuPlastVoltage: Procedures and Targets, Deliverable 3.1, 3.2 , June 2010, p. 13, 37

108 EuPlastVoltage: Procedures and Targets, Deliverable 3.1, 3.2, June 2010, p. 35-37

io reduces the total energy consumption only slightly in comparison to the energy cost driven reference scenario. In comparison to a business-as-usual scenario 7,000 TJ savings might be achievable, but approximately half of this potential is achieved with retrofitting measures to improve machinery, which is already in operation.

Table 1-24: Scenarios for extrusion (EU energy consumption)

Scenario	2007	2020
Frozen, i.e. Business-as-usual (in TJ)	79,000	97,000
Reference (in TJ)	78,000	91,000
Voluntary agreement (in TJ)	78,000	90,000

By comparing extrusion machines of different ages at an Austrian extrusion company, it became evident that newer machines have lower specific energy consumption, due to better insulation of cylinders, more efficient drives, optimized internal heating system, and reduction and elimination of ancillary components[109].

Blow Moulding

Major energy consumption of blow moulding is related to[110]

- Compressed air
- Cooling the products
- Hydraulic pumps
- Heating and cooling

60% of the energy consumption in blow moulding machines is related to compressed air supply. Energy can be saved by working with the correct pressure, selecting a well seized compressor and by minimization of leaks. If diverse processes need compressed air, best practice is to take one compressor for several machines – but this recommendation goes beyond the boundaries of the moulding machine as such.

Optimisation of the hydraulic system, in particular measures to adapt energy consumption to the cycle times, is an important field for machinery improvements. Similarly, an

109 Pamminger, R.; Wimmer, W.; Winkler, R.: Entwicklung von Kriterien zur Kommunikation der Energieeffizienz von Kunststoff verarbeitenden Maschinen, 5/2010 p. 70

110 RECIPE: Low Energy Plastics Processing – European Best Practice Guide, October 2006, p. 35-37

all-electric machine with state-of-the–art energy saving options is stated to result in significant energy savings.

Total savings for the scenarios calculated by the EuPlastVoltage project are summarised in Table 1-25 for blow moulding[111]: The more ambitious “voluntary agreement” scenario reduces the total energy consumption only slightly in comparison to the energy cost driven reference scenario. In comparison to a business-as-usual scenario 5,000 TJ savings might be achievable, but the largest share of this potential is achieved with retrofitting measures to improve machinery, which is already in operation.

Table 1-25: Scenarios for blow moulding (EU energy consumption)

Scenario	2007	2020
Frozen, i.e. Business-as-usual (in TJ)	38,000	47,000
Reference (in TJ)	37,000	43,000
Voluntary agreement (in TJ)	37,000	42,000

Other plastics converting processes

There are several more plastics converting processes with typical power consumption attributes and related improvement potentials, but as injection moulding, extrusion and blow moulding are the most relevant processes, this screening is limited to these three types of processes. Only for illustration some additional aspects are listed here:

- Rotational Moulding: Electrical mould heating is potentially much more efficient than convection ovens[112]
- Thermoforming: Gas versus electricity heating has an impact on heating times, thus throughput, but at a potentially higher total energy consumption[113]

Total Savings Potential in Plastics Processing

In sum plastic converting industry can save energy by about 92,000TJ[114]. The largest potential in energy savings is related to injection moulding, according to findings of the

111 EuPlastVoltage: Procedures and Targets, Deliverable 3.1, 3.2, June 2010, p. 38-39

112 RECIPE: Low Energy Plastics Processing – European Best Practice Guide, October 2006, p. 43

113 RECIPE: Low Energy Plastics Processing – European Best Practice Guide, October 2006, p. 47

project EuPlastVoltage. However, part of the potential is linked to cross-cutting technologies (e.g. optimized central cooling or pressurized air systems) and is therefore not related to design measures targeting directly at the plastics processing machines. A major share of the potential is also related to retrofitting measures.

As a result of the “frozen” scenario the energy consumption would increase massively to 258,000 TJ in 2020. Taking into account a sensitivity of the market for energy costs, the energy consumption would remain on a stable level (“reference scenario”). Only the scenario of a voluntary agreement[115] results a reduction of energy use by around 19%. From 2010 to 2020 the saving potential is still in the range of 14%.

Table 1-26: Summarised scenarios for plastics processing (EU energy consumption)

Scenario	2007	2020
Frozen, i.e. Business-as-usual (in TJ)	210,000	258,000
Reference (in TJ)	>200,000	>200,000
Voluntary agreement (in TJ)	195,000	158,000

<u>EUROMAP study</u>

Partly in response to the initial discussions on plastics processing machinery, EUROMAP contracted a parallel study to investigate the status quo of these machines and related savings potentials. The following findings have been published by EUROMAP[116]:

“The study looked at the main plastics and rubber processing technologies, i.e. injection moulding, extrusion, blow moulding and thermoforming, which account for around 90 per cent of the total volume processed. (...) production efficiency has almost doubled in 20 years, and plastics machinery’s specific energy consumption is down 30 per cent. (...). The demands made on hydraulic systems have resulted in greater efficiency and cut the energy consumption of injection moulding machines by around 40 per cent. The throughput capacity of extrusion machines has also doubled over the same period.

114 EuPlastVoltage: Procedures and Targets, Deliverable 3.1, 3.2, June 2010, p. 41-42

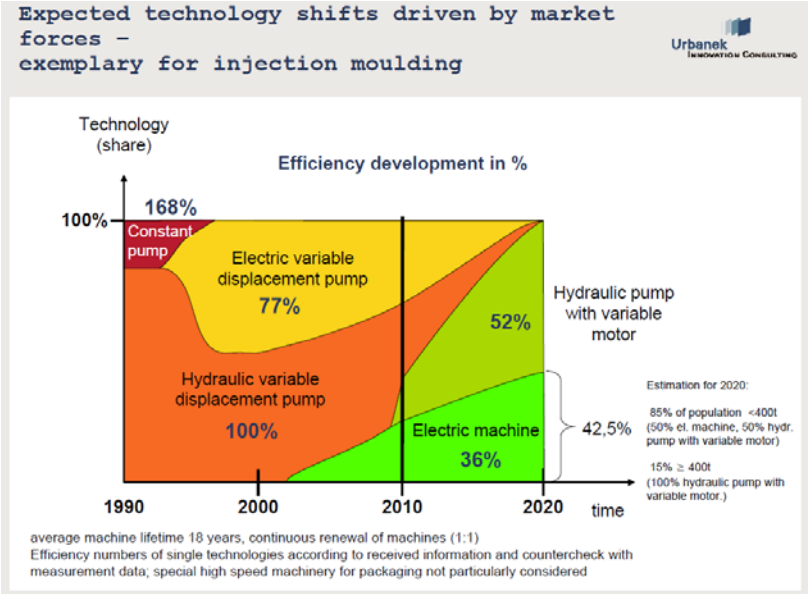
115 To be understood synonymous to any policy measure, that results in an implementation of state-of-the-art technical options at large

116 EUROMAP: study: productivity and energy efficiency go hand in hand, press release, 29 November 2011, and Urbanek, O.: EUROMAP Energy-Efficiency-Study, Summary/Conclusions, 9 June 2011; full study was not available to Fraunhofer, so no verification of claims made can be done

Machine-related energy consumption has been reduced by around 20 per cent. The same is true in compounding: twice the amount of material is being processed with machine-related energy consumption down by 20 per cent at the same time. (...) Increasing use has been made of servo drives in cyclic processes such as injection moulding, blow moulding and vacuum forming technologies for a number of years now. These allow the energy required for motion to be cut by half. Plants with a conventional, central power source and system-related line and control losses are increasingly being replaced. (...) Servo systems now also offer simple solutions for energy recuperation. In injection moulding, for example, during rapid motion of the closing units, the drives are used as generators to produce energy when braking. The same principle is also used with fast-working closing units of blow moulding machines and in thermoforming machines. (...) Looking to the future, there is no doubt that the use of energy-saving and highly dynamic components will provide a significant boost in terms of improving energy efficiency further in the next ten years. Greater use of all-electric drives and servo-hydraulic designs instead of conventional technology will pave the way for further efficiency gains – in some cases as much as 50 per cent. (...) The most important part in improving machinery is played by developments in process engineering: advances in screw technology have brought a significant increase in throughput rates while at the same time improving the quality of the melt. This has allowed extruders and the injection units of injection moulding machines to become smaller and better while maintaining performance. Radiant heater systems show great potential in thermoforming machines. There is also a great deal of potential for combining several processes: this is of particular interest if residual heat from one stage in a process can be used in the following stage with a view to eliminating reheating altogether. (...) Major savings can also be achieved if converters fine-tune processes to minimise energy consumption. Monitoring the flow of energy in machines, installations and in the plant also produces results. It makes the energy requirement transparent, which in turn contributes to tailoring energy consumption to need. (...)"

The main technology trends, which yield significant savings are depicted in Figure 1-20.

Figure 1-20: Expected technology shifts for injection moulding (source: Urbanek)



The total site energy consumption (S-EC) of the European plastic converting industry (thermoplastics, 2008) is stated to be 66,5 TWh. Machinery energy consumption (M-EC) totals in 22,5 TWh[117], which equals 236 PJ Total Energy consumption[118], and which almost exactly corresponds to the figures stated by the EuPlastVoltage project above.

Urbanek concludes that

- *"the 20% EU goal [for energy consumption reduction] will be achieved by renewal of the machine population with the latest state-of-the-art technology.*
- *In order to optimize energy consumption in plastics processing, the complete product-specific production environment around converting machines must be considered and monitored.*
- *There is great potential in the area of heat recovery."*

Given these statements, a significant savings potential for plastics processing machinery can be concluded. The study gives the impression that this development is inherently related to market developments. The information provided by EUROMAP does

117 Urbanek, O.: EUROMAP Energy-Efficiency-Study, Summary/Conclusions, 9 June 2011

118 Based on MEEuP indicators: 1 MWh electricity equals 10500 MJ Total Energy

not indicate whether there is any additional savings potential, which would require dedicated policy measures to be realised.

Standardization

The European association EUROMAP developed a standard for **Injection Moulding Machines – Determination of Specific Machine Related Energy Consumption** (EUROMAP 60), i.e. covering roughly a production volume of 6,400 machines in 2009 in EU-27 (see PRODCOM figures above). The current version 2.0, published in June 2009, is currently tested by a couple of machinery manufacturers. The scope of this standard is restricted to “injection moulding machines for thermoplastics with one injection unit with a reciprocating screw, an electrically heated barrel and one horizontal clamping unit without any ancillaries”. The standard defines the set-up conditions for measurements and three types of production cycles for thin-walled parts, technical parts and commodity parts / thick-walled parts. In technical documents the following values shall be given:

- Specific machine related energy consumption (kWh/kg)
- Average power consumption (kW)
- Cycle time
- Power factor cos φ

Consequently, for an injection moulding machine the technical documentation should include e.g. the following:

> Specific energy related energy consumption (EUROMAP 60), Cycle II:
> 0,95 kWh/kg; 20 kW; 30 s; cos φ = 0,85

It is worthwhile noticing, that EUROMAP 60 refers to the amount of processed plastics (“per kg”), which is a suitable reference unit for thermal primary shaping processes, such as moulding, but rather not for forming, cutting, joining technologies.

Furthermore, injection moulding is only a sub-segment of the plastics processing industry. For extruding a similar approach is under discussion (EUROMAP 90) and a working group was established, but by now no consensus regarding a feasible energy efficiency measurement standard could be achieved.

Conclusions

This screening leads to the following conclusions for this study:

- Plastics and rubber machinery is an important market segment in terms of installed number of units
- Technically there are major differences compared to “machine tools” as heating and cooling are relevant and process inherent power consuming machine features,
    - which are subject to some significant directly machinery related improvement potentials
    - but typically are not found in “machine tools” and thus could not be tackled with similar approaches.
- Consequently, plastics processing machinery is not considered a “machine tool”
- On the component / module level there are some similarities with “machine tools”, in particular regarding
    - Drives
    - Hydraulic systems
    - Vacuum and pressurized air systems
    - Control systems

  although with some specifics (hydraulic oil is much more subject to a significant heat transfer from the process, pressurized air used for blow moulding has no similar key function in “machine tools”), which need to be taken into account in later steps of the study.
- Consequently, **drives, hydraulic systems, pneumatic systems / vacuum and pressurized air systems, control systems of plastics processing machinery are within the scope of the study on the modular level**.
- Approaches for energy efficiency measurement standards are in place or under discussion for certain market segments, but
    - need further verification regarding feasibility and
    - explicitly follow an approach (referencing the amount of material weight processed), which is not comparable to cutting or forming processes

1.1.5.5 Specification of environmental aspects of machine tools

1.1.5.5.1 Environmental parameters

Taking into account available life cycle data (see above) a first descriptive screening of machine tools regarding environmental parameters as listed in Annex I of the ErP directive is provided in Table 1-27, with further explanations provided below the table.

Table 1-27: Environmental parameters and judgement of relevance

parameters according to Annex I, 1.3 of EuP framework directive	**Relevance**
(a) **weight and volume** of the product	low relevancy
Material consumption mainly determined by mechanical requirements; many machine tools are in the range of several tons, so high consumption per device, but limited improvement potential: There are some approaches to make use of light-weight materials and to reduce weight of moving parts (reducing also the power requirements). Volume of machine tools determined mainly by size of work pieces to be processed, but anecdotally there are machine tools manufacturers claiming to have achieved a significant reduction in machine size. Environmental assessments of 3rd parties indicate a low relevancy of material consumption (and thus weight) of machine tools regarding the whole life cycle. Impact is in the range of few percent of the whole life cycle impact in most impact categories.	
(b) use of **materials issued from recycling activities**;	low relevancy
Metal parts typically made of the usual primary / secondary metals mix as provided by the metals industry.	
(c) **consumption of energy, water and other resources** throughout the life cycle;	Energy: highest relevancy in operational and non-operational modes Water: low relevancy
Environmental assessments of 3rd parties typically identify the use phase consumption of energy as the most relevant environmental aspect of machine tools over their life cycle. Given the high power rating of many machine tools (in the range of up to several 100 kVA, see VDW survey above), long lifetime and long operation times in most manufacturing environments, power consumption is high. Some machine tools, such as machine tools for soldering and welding also operate at elevated temperatures, meaning additional power consumption. Numerous approaches for reducing power consumption of machine tools are stated in literature and are promoted by solution providers, so a significant improvement potential can be assumed. Measures are as follows: power management, efficient motors, etc. Note, that a major share of power consumption depends on the work piece (geometry, precision requirements) and the material to be processed, thus is not subject to machine related improvement options. Consumption of pressurized air could be relevant in terms of power consumption (e.g. for pneumatic tables). Usage of water occasionally as process cooling water and to generate emulsions and solutions of cooling lubricants. (Reduction potential for usage of cooling lubricants see below)	
(d) **use of substances classified as hazardous** to health and/or the environment (...);	Low relevance

<table>
<tr><th>parameters according to Annex I, 1.3 of EuP framework directive</th><th>Relevance</th></tr>
<tr><td colspan="2">Hazardous substances used as constituent of machine tools are e.g. lead in solder of electronics components (exempted from RoHS in case of stationary equipment) and mercury in operator panel backlights.

Given the trend towards RoHS compliant electronics components in general, availability of non-RoHS compliant components for machine tool applications also is hampered, stimulating a “voluntary” change to leadfree soldering technologies

There is no known environmental assessment available indicating any environmental relevancy of hazardous substances contained in parts and components of machine tools. Also given the B2B nature of the machine tools market, uncontrolled release of lead from solders etc. is unlikely.</td></tr>
<tr><td>(e) quantity and nature of consumables needed for proper use and maintenance;</td><td>Consumption of lubricants: moderate relevance

Consumption of hydraulic oils: low relevance

some cooling lubricants contain toxic composites</td></tr>
<tr><td colspan="2">Although consumption of cooling lubricants and hydraulic oils can be significant, they do not show up as very relevant in 3rd party environmental assessments. Total consumption of cooling lubricants is estimated at several million tonnes per year (emulsions and solutions, see task 2 report, 2.4.3). There is an improvement potential in reducing cooling lubricants consumption by employing minimum quantity lubrication (MQL) or dry processing, but this might affect power consumption of the machine tool adversely.

less toxic alternatives available, but not suitable for some dedicated processed metals /alloys</td></tr>
<tr><td>(f) ease for reuse and recycling as expressed through:
• number of materials and components used,
• use of standard components,
• time necessary for disassembly,
• complexity of tools necessary for disassembly,
• use of component and material coding standards for the identification of components and materials suitable for reuse and recycling (including marking of plastic parts in accordance with ISO standards),
• use of easily recyclable materials,
• easy access to valuable and other recyclable components and materials;
• easy access to components and materials containing hazardous substances;</td><td>Moderate relevance</td></tr>
<tr><td colspan="2">As machine tools represent high-value investment goods reuse usually is done, but availability of suitable control electronics typically is hampered for machine tools > 10 years in operation, but this is rather a problem of spare parts stock, not machine design.

As maintenance-friendliness of machine tools in most applications is crucial for reduced down-times, access to key components and possibility for replacement usually is non-critical. Machine tools usually are designed in a modular way easing also disassembly and materials separation at end-of-life.

Usage of bulk materials, which are of interest for metals recycling at end-of-life. Amount of metal make it worthwhile typically to dismantle machine tools.

Contamination of machines in some applications requires thorough decontamination before material recycling and resale.</td></tr>
<tr><td>(g) incorporation of used components;</td><td>Low relevance</td></tr>
<tr><td colspan="2">Given the long lifetime of machine tools possibilities are limited that components from another machine tool are still usable / state-of-the-art / compatible for a new machine tool</td></tr>
<tr><td>(h) avoidance of technical solutions detrimental to reuse and recycling of</td><td>Low relevance</td></tr>
</table>

parameters according to Annex I, 1.3 of EuP framework directive	Relevance
components and whole appliances;	
Non-standardised components and interfaces constitute a barrier for reuse of components and whole machines. E.g. proprietary communication protocols can be considered a barrier, but see remarks on reuse of machine tools in general above.	
(i) **extension of lifetime** as expressed through: minimum guaranteed lifetime, minimum time for availability of spare parts, modularity, upgradeability, repairability;	Moderate relevance
Usually machine tools are compliant with essential requirements for lifetime extension as demonstrated also by the huge second hand market for machine tools.	
(j) amounts of **waste** generated and amounts of **hazardous waste** generated;	Moderate relevance
Major wastes generated throughout product usage and disposal are: Cut-offs from workpieces, yield losses of workpieces, emissions from work pieces such as wood particle boards and from processes such as welding fumes and saw dust, waste from cooling lubricants and machine oils, WEEE from electronic components, scrapped tools. Some of these wastes could reach a moderate level of relevance.	
(k) **emissions to air** (greenhouse gases, acidifying agents, volatile organic compounds, ozone depleting substances, persistent organic pollutants, heavy metals, fine particulate and suspended particulate matter) (...);	Moderate relevance
Particle emissions from wood processing (saw dust) constitute a major environmental problem for the workplace, same for welding fumes and the like. The emergence of oil mist and subsequently oil steam is a prevalent observable phenomenon during metal cutting operations under high cutting rates. The discharge of gaseous oil causes significant damage to the immediate environment. Due to the fact that there is existing legislation regulating the maximum admissible concentration, machine tools generally are in possession of an oil mist extraction device. Thus, the environmental relevancy is assumed to be low. Lower relevancy of droplets emitted from cooling lubricants usage. Relevant emissions to air throughout the life cycle are rather related to the power consumption (emissions of power plants).	
(l) **emissions to water** (heavy metals, substances with an adverse effect on the oxygen balance, persistent organic pollutants);	Low relevance
Cooling lubricants are typically classified as water hazard substances, but no release under normal operating conditions. Waste water (containing e.g. residues of cooling lubricants) stems from cleaning of machined parts, thus dry processing could reduce cleaning requirements.	
(m) **emissions to soil** (especially leakage and spills of dangerous substances during the use phase of the product, and the potential for leaching upon its disposal as waste).	Low relevance
No release of any hazardous substances under normal operating conditions to be expected.	

1.1.5.5.2 Criteria for the judgement of the environmental relevancy

As revealed above, according to 3rd party findings, the major environmental impact is induced during the use phase, notably caused by the consumption on electricity. In this respect, the following criteria have been summarized, reflecting the environmental parameters identified above, which are energy consumption, compressed air consumption, consumption of cooling lubricants, cooling water consumption, exhaust air from suction, workspace related air conditioning, and noise pollution.

Energy consumption

In the framework of the environmental screening, the energy consumption of a machine tool is a matter of special importance. In accordance with the Working Plan study, most machine tools are indicated using a great deal of energy during operation time.[119] The majority of metal working machine tools operate in the range of 30KW-60KW, whereas this window might not be reliable considering the multitude of distinctive machine tools in the product scope. Connecting power of other relevant machine tools, explicitly those for working wood are likely to be significantly lower in average. However, energy consumption remains being a central benchmark in the assessment of environmental impacts, including losses due to stand-by mode.

The energy efficiency of a machine tool is likely to be a significant subject matter in this Product Group Study. As 30% of the energy consumption is used for standby-mode (e.g. in order to maintain the process stability),[120] concepts for economic usage are gaining additional attention.

According to a study on environmental machining from 2004, three different types of machine tools where analyzed in regard to the specific energy use under heavy duty.[121] As a result, a rising degree of automation seems to be in correlation to a rising fixed percentage of constant energy consumption:

119 EPTA LTD, ref 13, p. 258f.

120 BUNDESMINISTERIUM FÜR BILDUNG UND FORSCHUNG (BMBF), FRAUNHOFER GESELLSCHAFT (FHG), *Energieeffizienz in der Produktion*, 2008.

121 DAHMUS, J.B., GUTOWSKI, T.G., *An Environmental Analysis of Machining*, 2004.

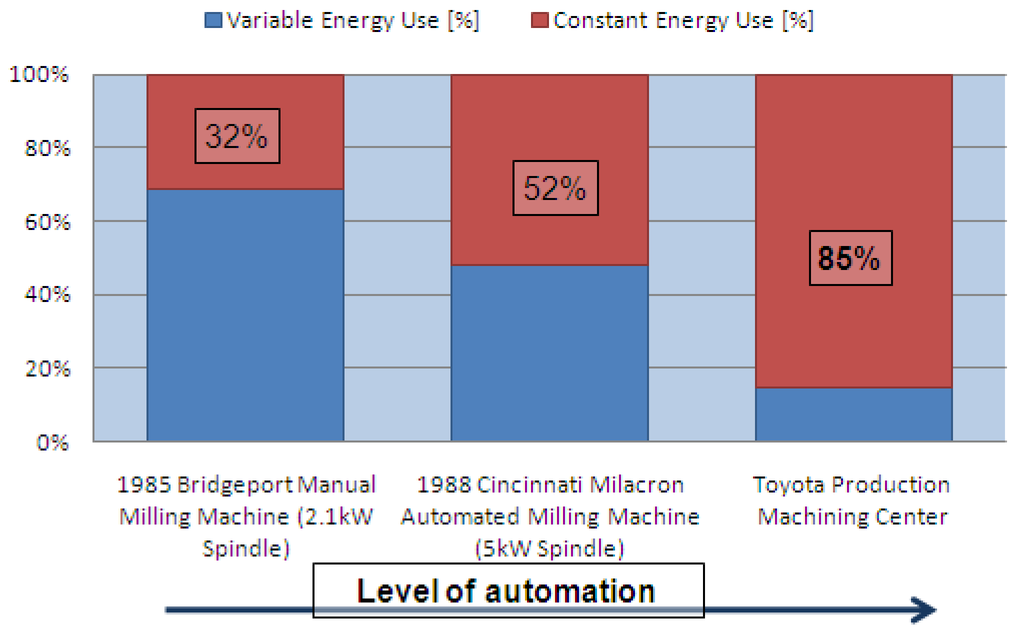


Figure1-21: Ratio of fixed and variable energy consumption for different types of machine tools (selection), figure adapted from Dahmus & Gutowski.

Compressed air consumption

Closely linked to energy efficiency of production systems is the supply and consumption of compressed air. Overall, possible savings can be up to 30% of the current energy consumption.[122]

Consumption of cooling lubricants

By the means of ISO 19378:2003,[123] cooling lubricants for metal-cutting procedures are differentiated as being water-miscible, water-immiscible, or water-mixed fluids. To extend the field of appliance, different lubricants contain several additives in order to make them suitable for the respective kind of metal cutting. The substances can be classified in groups as follows:

- Anti-wear additives which form a lubricating film (AW additives),

122 BUNDESMINSITERIUM FÜR WIRTSCHAFT UND ARBEIT (BMWA), DEUTSCHE ENERGIE-AGENTUR GmbH (DENA), FRAUNHOFER ISI, VDMA KDV, *Druckluft Effizient – Abschlussbericht*, 2005.

123 INTERNATIONAL ORGANIZATION FOR STANDARDIZATION, *ISO 19378:2003 - Lubricants, industrial oils and related products (class L) -- Machine-tool lubricants -- Categories and specifications*, 2003.

- High pressure additives, so-called EP additives,
- Anticorrosion additives,
- Foam retarding agents,
- Anti-fog materials,
- Dispersing agents, and
- Surface-active substances.

The ecological range due to the use of cooling lubricants has its impact on several distinctive levels, both in the direct working surrounding as well as in a globally-viewed framework, which is visualized in Figure1-22. Cooling lubricants have a broad ecological range, which is due to presence of hazardous substances for human and environment, especially in form of aerosols, besides causing additional costs and charges. To avoid dissipation of aerosols, auxiliary equipment such as filtration units need to incorporated. Furthermore, specific requirements concerning environmentally compatible recycling are obvious, contributing to an increase in life cycle costs of lubricants.

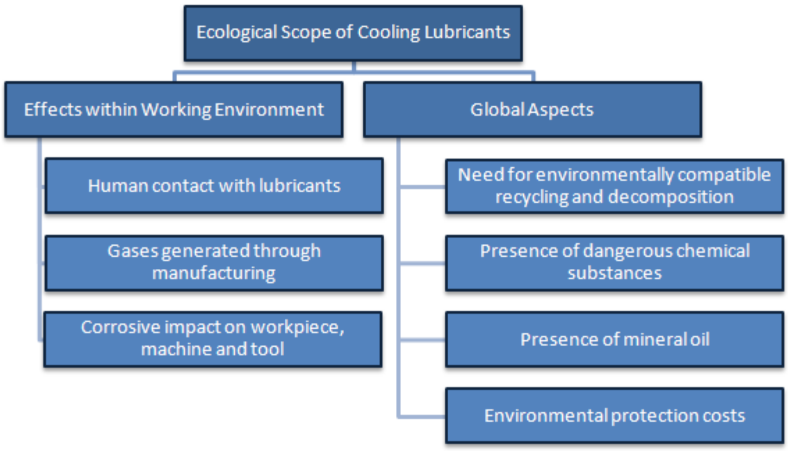


Figure1-22: Ecological scope of cooling lubricants. Figure adapted from Sokovic & Mijanovic.[124]

Cooling water consumption

The assessment of the water consumption adds another component in order to gain an overall picture of the environmental relevancy of machine tools.

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124 SOKOVIC, M., MIJANOVIC, K., *Ecological aspects of the cutting fluids and its influence on quantifiable parameters of the cutting processes*, 2001.

Except for the appliance of lubricants, water may be used in several processes as the cooling media during manufacturing. Considering the environmental interaction, we will focus on machines which cooling systems are based upon an open loop mechanism, where a mass transfer across the system boundaries can be quantified. Furthermore, impacts caused by potentially harmful additives contained in the cooling media as well as the dissipated energy content have to be considered.

Exhaust air from suction

As with the previous indicator, the mass transfer caused by the exhaust air of the manufacturing process will be assessed by an energetic as well as a material related consideration. Closely related to water consumption, the quality respectively the composition of accompanying substances (e.g. aerosols deriving from the cooling process) is of great importance, considering that additional modules (e.g. sophisticated filtration plants) need to be taken into account, which in return affects the life cycle assessment of the machine.

Workspace related air conditioning

The additional air conditioning may occur in places where the ambient air temperature is raised by the dissipated energy from the running machines. As an indirect influence considering the efficiency of these devices, further energy consumption for room air-conditioning have to be taken into account for the assessment. The other way around, extra energy is needed to maintain a solid temperature in a working environment. Especially when regarding large scale factories, room ventilation is accounted for as an important expense factor. Empirical evidence is provided in the frame of an energetic analysis carried out at BMW in Leipzig, in which potential savings of 457.000€ per annum were revealed.[125]

Noise pollution

Noise pollution resembles a location based disruptive factor, leading to physiological discomfort and psychological distress of beings that are at close range. With this aspect in mind, machine tools and where appropriate single components such as the spindle and the electric motor needs to be evaluated regarding emitted noise.

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125 HAHM, *Verbindung von Energieeffizienz und Energiebezug in produzierenden Unternehmen*, 2010, slide 27.

Due to the fact that noise emission and methods for standardised measurement has long been subject to standardisation, which will be discussed in detail in task 1.2, the subject of noise pollution will not be further regarded in this study. In particular noise is covered under the machinery directive.

1.1.5.6 Prioritising machine tool categories

- **Objective**

In order to conduct a first differentiation of scope related machine tools on the grounds of environmental relevancy, the identified PRODCOM categories are classified in terms of the level of automation (see 1.1.1.2). The screening additionally intends to identify categories of minor market relevance.

- **Preliminary consideration**

Across the entire machine life, complex and highly automated machine tools cause higher cumulated power consumption than “low tech” machine tools. This is due to the fact that highly automated machine tools are most frequently used for series production and the like, whereas “low tech” machine tools more likely are sporadically being operated. In this regard, the price (single value) of the machine is used to draw conclusions concerning its level of complexity.[126] We presume, that a high value reflects a high complexity and thus a higher level of automation of the product. Thus, we estimate that a high level of complexity is correlated to an increasing ecological impact and vice versa. This is confirmed by a screening of connection power correlated with sales prices.[127] A classification in terms of automation is of particular interest when discussing improvement options for these machines. It is acknowledged that the increase of automation goes along with a growth of environmental impact respectively energy demand per machine, considering that more components and different technologies are involved. It is however also acknowledged, that on a “per unit of product” basis a highly automated machining centre is likely to be more efficient, than smaller machine units. This will be reflected in later tasks.

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[126] Note: The price classification is not committed to any representative market data but intends to find reasonable groups on the basis of the range of prices as depicted in PRODCOM.

[127] Note: However, it should be considered that on the other hand, automation goes along with a significant raise in productivity.

The basic assumptions are summarized in Figure 1-23.

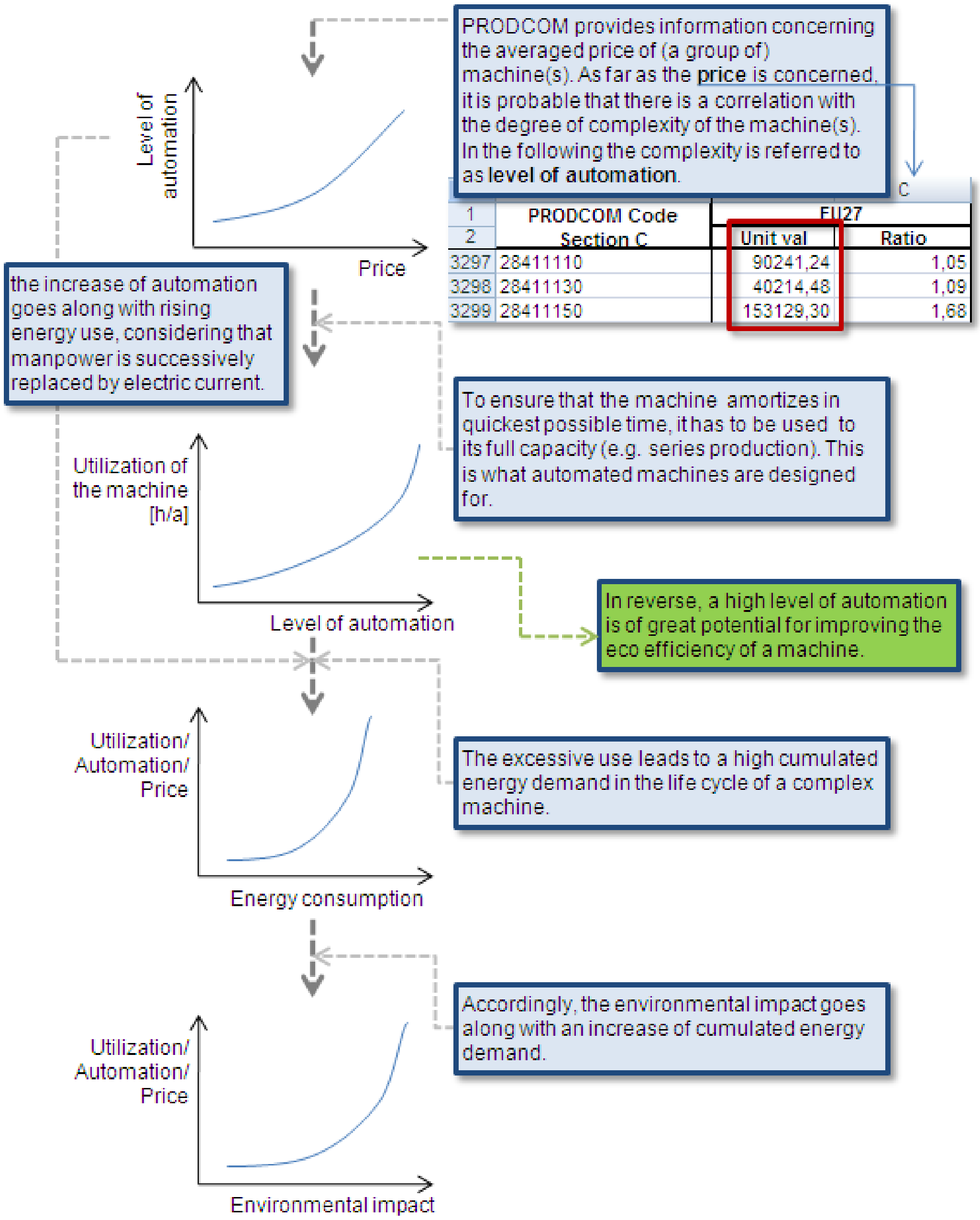

Figure 1-23: Basic assumptions for the first environmental screening.

- **Limitations**

The assessment of metal forming machinery (i.e. NACE code 28.41) is facilitated by the aid of specified information provided by CECIMO which makes it possible to distinguish NC from non-NC. As far as the other types of machine tools are concerned, the distinction according to automation is additionally being hampered due to several limitations, which are high level of aggregation, unclear descriptions, etc.[128]

It is acknowledged, that several categories are lacking reliability in regard to the economic data and therefore are in need of a review. As far as metal working machine tools are concerned, it should be pointed out that the economic figures (sold volume and unit value) derives from a plausibility check and related revision of PRODCOM data (further explanation is given in task 2). Accordingly, market statistics from the other non-revised machine groups should be used with caution.

- **Means**

The procedure is being performed separately for metal working machine tools, woodworking machines, welding machines, and other machine tools. The screening is not applied on those which are identified as related machineries (see Annex III – Related machinery (identified modules) (non-exhaustive)), considering that only specific modules will be of interest for this study.

Categories which obviously cover machinery and equipment portable by hand (particular low value as an indication) and which are primarily not for industrial use will be not relevant anymore in the ongoing course of the study. In this regard, categories respectively machines which have been recognized as not relevant during the screening are listed separately at the end of each screening.

Considering that PRODCOM categories deriving from classes 28.41 and 28.49 are not unambiguously defined in terms of automation, further criteria need to be considered (see Table 1-28).

128 Note: For details, see limitations for classifying the product scope.

Table 1-28: Level of automation for the environmental screening – Necessary criteria for identification

Number	Description	Criteria
5	System	Declared as such.
4	Cell	1. Declared as such. 2. If not applicable: If a particular type of machine is addressed, category can be matched to a specific level of automation (further explanation mandatory). 3. If not applicable: Not declared and single value **> 300.000€.**
3	Centre	1. Labelled as such. 2. If not applicable: If a particular type of machine is addressed, category can be matched to a specific level of automation (further explanation mandatory). 3. If not applicable: Not declared and single value **100.000 - 300.000€**.
2	NC-Machine	1. Labelled as such. 2. If not applicable: If a particular type of machine is addressed, category can be matched to a specific level of automation (further explanation mandatory). 3. If not applicable: Not declared and single value **10.000 - 100.000€**.
1	Machine	1. Labelled as non-NC machine by CECIMO. 2. Labelled as such. 3. If not applicable: If a particular type of machine is addressed, category can be matched to a specific level of automation (further explanation mandatory). 4. If not applicable: Not declared and single value **< 10.000€**.
0	No level determinable	See individual comment for each category.

- **Findings for the environmental screening**

The results of the environmental screening in terms of level of automation are summarized in Annex IV – Environmental screening of product scope. Within each level, the PRODCOM categories are in a descending order, according to the sold volume.

Metal working machine tools

The results for metal working machine tools are displayed in **Table 6-1**.

Woodworking machines

The results for woodworking machines are depicted in **Table 6-2**. For simplicity, machines not related to the category are crossed out in the screening.[129]

[129] Note: Explanation is given during the course of classifying woodworking machines (1.1.3.2).

Welding, soldering, and brazing machines

The results for welding, soldering, and brazing machines are depicted in **Table 6-3**.

Other machine tools

The results for other machine tools are depicted in **Table 6-4**.

1.1.5.7 Summary and conclusions

Previous research on the ecological performance of machine tools reveals that the life cycle impact largely derives from the **use phase**, notably **energy consumption**. To some extent, the use of cooling lubricants and hydraulic oil also contributes to the ecological performance. Some studies indicate that under certain use conditions and for certain processes the use phase might be less dominating and the **production phase** of the machine tool, i.e. material consumption for constructing the machine, is relevant as well. The analysis also shows that weight and connection power among machine tools are heterogeneous, meaning that machine tools (also those which share the same PRODCOM category) have very specific ecological impacts and individual improvement potentials.

Based on our findings, the relevance of certain parameters set out by the ErP Directive could be determined.

As a result, machine tools having a comparative high energy demand will be put into focus, e.g. those with a high level of automation (considering that a multitude of modules are involved which contribute to an increased energy demand of the machine) or those which are permanently operated (almost constant energy demand at any time of the day). These types of machine tools are of particular interest for the later base case assessments.

1.1.6 Functional Unit

The functional unit in accordance with ISO14040 on LCAs is “the quantified performance of a product system for use as a reference unit in life cycle assessment study”. A functional unit is meant to allow for a comparison of different products and to provide an unambiguous reference basis for the LCA results of the product assessment.

Given the complexity of potential functions provided by any machine tool (in terms of workpieces to be manufactured) it seems feasible to take “one machine tool over its full life cycle” as functional unit. This approach is also followed by CECIMO in their preparatory LCA work and the SRI developments.

VDMA in a stakeholder comment objects the approach to define the whole machine tool as a “functional unit” as defined in EN ISO 14040 for the following reasons, and questions the possibility to define a functional unit for this broad product range at all: “In principle, VDMA strongly favours the extended product approach that takes into consideration the operating conditions and use patterns of the product involved. By doing so, usually a fixed unit will have to be studied, taking into consideration the actual product, composed of a motor and the control unit. In marketing this unit the manufacturer assumes "overall responsibility". … Metal processing machine tools are complex systems and are marketed as an asset to companies who actively influence the technical characteristics, performance data and equipment characteristics of the machine tool. Therefore, these products are highly unique, influenced by the customer’s requirements with regard to the end product as well as by the organisational and manufacturing involvement in the customer’s production technical environment. In addition, metal processing machine tools encompass an extremely wide range of different processing technologies, with approximately 400 machine groups and around 2000 different types of machines, meaning that any technical/technological comparability between them is extremely difficult. The requirement of EN ISO 14040, to use a “functional unit” for a Life Cycle, is not applicable to a machine tool due to its various application scenarios.”

A more appropriate unit than the machine tool as such for comparisons would be actually the product output. If the product output is not taken into account at all, productivity of a machine tool is neglected. This is not intended by ecodesign as on a highly automised machining centre a high number of machined parts can be produced, but power consumption per machining hour is high, whereas a smaller, less automated machine is likely to run with lower power consumption per machining hour. However, typically power consumption per workpiece produced is typically higher on a smaller machine. This needs to be reflected in the study.

Having said that, the definition of a functional unit for “machine tools and related machinery” per product output in general is not possible, given the manifoldness of manufacturing tasks and the variety of quality criteria to be met. Even more, machine tools are typically meant to manufacture a multitude of different forms and sizes of workpieces throughout their lifetime and a “standard product” can hardly be defined, if production reality should be reflected.

Technical parameters (selection) which are relevant to define the manufactured product comprise:

1. Processed material
2. Type of processing (forming, bending, cutting, drilling etc.)[130]
3. Processing accuracy (failure tolerance etc.)
4. Workpiece dimensions
5. Specific production environment requirements (e.g. processing in clean rooms)

If at all, an output related functional unit can be defined only for certain processes, e.g. possibly for welding “1m welded joint of a given quality for a given geometry” – but this already makes clear, that quality criteria are inevitable for a fair comparison of different machines. For chip removal processes the amount of removed material could be a theoretical functional unit, but as to be complemented by a clear definition of the material to be processed, geometry, and quality criteria, but even then a distinction has to be made for micro machining versus bulk processing, as the latter is meant to remove more material per se, and micro machining is optimised for meeting certain product specifications. The approach to refer to the amount of material processed seems to be feasible only for primary shaping processes (such as injection moulding of plastics, EUROMAP 60, but even in this case comparability of measured performance values is questionable); however, primary shaping is not in the scope of this study. For bending operations Santos et al.[131] propose an exergy reference unit, as the amount of material is considered inappropriate.

In conclusion, for practical reasons this study has to refer to **one machine tool** as a general functional unit, but **productivity** needs to be considered when interpreting the outcomes of the assessments.

130 In machining centers several of these processes are performed consecutively

131 Santos, J.P. et al.: Improving the environmental performance of machine-tools: influence of technology and throughput on the electrical energy consumption of a press-brake, Journal of Cleaner Production (2010)

1.2 Test and other standards

This task should identify the relevant test and other standards relevant for machine tools. Compliant with our previous structure, this task copes with general environmental standards on machinery with particular attention to metal working machine tools, woodworking machines, as well as welding, soldering, and brazing machines. Technical standards – and test standards in particular – are important elements with respect to eco-design requirements and in order to proof compliance.

The objective of this subtask 1.2 is to give an overview of existing test standards, provide short explanations of vital test procedures, and additional information on sector-specific standards (e.g. quality issues) for the product scope defined in task 1.1.

International standards will be taken into consideration for the analysis, comprising e.g. ISO standards, but also those of certain industry branches, which use machine tools, such as the SEMI standards for the semiconductor industry. It is worthwhile noticing, that the semiconductor industry already published a couple of outstanding Environmental, Health and Safety (EHS) standards and guides addressing environmental impacts specifically (namely end-of-life, energy conservation – also with a systems perspective – etc.).

1.2.1 International standards

There are few standards addressing environmental issues on international level, notably in the field of lubricants and lubrication as well as noise measurement procedures. In this regard, there are several standards released on a general as well as on a product specific level. As far as general standards are concerned, **ISO 11204:1997** – ***Noise emitted by machinery and equipment – Measurement of emission sound pressure levels at a work station and at other specified positions – Method requiring environmental corrections –*** provides a method for the determination of sound pressure levels for machineries without the inclusion of specific environmental matters. Methods for noise measurements has been standardised in detail for several specific types of machines, which will be explained later.

1.2.1.1 Metal working machine tools

Lubricants and Lubrication

- **ISO 19378:2003** – ***Lubricants, industrial oils and related products (class L) – Machine-tool lubricants*** – ***Categories and specifications*** **–** provides information concerning the appropriate use of different lubricants for machine tool operation. However, the allocation of lubricants to the specific application is rather preceded by technological means instead of environmental issues, thus this standard has no direct environmental relevancy for machine tools. In extension to ISO 19378, **ISO 5170:1977** – ***Lubrication systems for machine tools*** **–** classifies and specifies lubrication systems in relation to the components of a machine in order to maintain a rational use of lubrication. Suppliers are advised to provide appropriate instructions for the correct use of lubricants in accordance to this standard. Although deriving from an applied perspective to reduce expenses due to inefficient lubrication, however, the standard considers toxic effects of lubricants and recommends restricted use of hazardous substances, thus an environmental dimension is provided.

Noise Measurement

- The issue of noise measurement is furthermore adapted by **ISO 230:2009** – ***Test code for machine tools – Determination of vibration levels***. As part 8 of this standard primarily deals with the origins of occurring vibrations due to machine tool operation, part 5 specifies the determination of sound levels, thus providing a pattern for the correct measurement of the emitted sound of a particular machine. In reference to ISO 230-5, determining the noise level of metal-cutting machineries are subject to **ISO 8525:2008 –** ***Airborne noise emitted by machine tools – Operating conditions for metal-cutting machineries.*** The standard focuses on certain machine tools for metal cutting procedures and provides specific introduction for certified noise measurement. By picking up these methods, comparability between similar types of machines shall be granted. It should be pointed out, that solely the test method itself is subject to the standards and hence the environmental aspect of sound emissions is disregarded. Further information, such as limitations of noise levels for different sort of machine tools, are not provided.

1.2.1.2 Woodworking machines

Noise Measurement

- **ISO 7960:1995** – ***Airborne noise emitted by machine tools – Operating conditions for woodworking machines*** – deals with test standard specifications for determining airborne noise emitted by various kind of woodworking machines. The standard provides a detailed instruction for measuring the noise of each specific type of machine. Aside from technical aspects concerning the measurement procedure, ISO 7960 does not relate to environmental relevancy of noise pollution, either.

1.2.1.3 Welding machines

DIN EN 14717:2005 – ***Welding and allied processes – Environmental check list*** **–** deals with general considerations for the inclusion of environmental aspects into welding processes. Primarily, it is intended to identify single root causes of environmental pollution triggered by welding processes, machineries and materials. The standard proposes the supervision of fumes, gases, and aerosols as well as the environmentally suitable disposal of substances such as scrap, dust, insulating material, and the like. Additionally, a list of actions to improve the energy efficiency is attached. However, it should be pointed out that DIN EN 14717 remains being on a general and qualitative level, subsequently there is a lack of precision concerning improvement measures (e.g. no specific technical guidance, etc.).

1.2.1.4 Environmental relevancy of safety standards[132]

There are numerous standards affecting safety regulations during design, construction and usage of machine tools on European level. Safety has been subject to standardisation in order to set up admissible working conditions for the operating personnel, especially in the field of metal working machine tools and woodworking machines. To name only a few important ones, such as **EN ISO 14121 –** ***Safety of machinery – Risk assessment*** **–** giving a methodology on risk analysis procedures or **EN ISO 12100 –** ***Safety of machinery – Basic concepts, general principles for design*** **–** featuring general guidelines concerning product construction matters, many standards provide particular behaviour patterns for secure handling of metal working and woodworking machines (such as DIN EN 692 on mechanical presses, DIN EN 693 on hy-

[132] Note: Due to structural reasons, some safety standards will be dealt with in other sections.

draulic presses, DIN EN 12415 on small numerically controlled lathes, etc.). Overlaps between safety standards and environmental aspects (e.g. as identified in task 1.1) can be assumed but not be acknowledged in detail at this point. However, to grant physical integrity for the operating personnel, safety standards will not be considered as “limits” for environmental implementing measures.

In terms of areal efficiency, **ISO 14122-1 – *Safety Machinery – Permanent means of access to machinery – Choice of fixed means of access between two levels* –** imposes certain rules for the safe access to machines. By defining the arrangement of particular access devices (such as ladders, stairs, ramps), the areal efficiency might be lowered due to this exogenous regulation. Furthermore, design and scaling of access devices cannot be optimized environmentally. However, besides that these circumstances apply rather to a small number of machine tools, the emerging consequences can be assumed as negligible.

ISO 14118:2000 – *Safety of machinery – Prevention of unexpected start-up* – deals with energy dissipation in order to reduce risk of accident from abrupt starts of machine tools and other machines. Therefore, the standard requires the dissipation of stored-energy (such as pressurized air, potential energy of machine tool components, e.g. hammer from a drop forged hammering machine). In doing so, usable energy is discharged and therefore a decrease in efficiency can be denoted. However, it can be assumed that the dissipated energy in comparison to the overall energy consumption is rather small. Certain aspects deriving from ISO 14118 might be of interested in regard to energy management systems which will be subject when analysing BATs in task 5.

As far as woodworking machines are concerned, **DIN EN 12779:2004+A1:2009 – *Safety of woodworking machines – Chip and dust extraction with fixed installation – Safety related performances and requirements* –** provides mandatory safety requirements for the use of stationary large-scale extraction units with air flow rates greater than 6.000 m^3/h. The standard covers several issues also relevant from an environmental point of view, i.e. noise emissions, selection of operation modes, and emissions of particles and gases. In regard to noise emissions, DIN EN 12779 recommends certain measures to be picked up during design and construction phase in order to reduce the general noise level of the dust extractor. A list of actions to reduce noise is given by the standard. Besides noise emissions, the document addresses energetic aspects of dust extractors. As a pneumatic system, the extraction vacuum has a major impact on the overall energy consumption. It is furthermore implied that naturally, a reduction of pressure losses in pipelines and tubes increases the energy efficiency. However, taking any measures in the field of energy consumption is not recommended.

Besides in standardisation, safety issues are a significant aspect in legislation. In regard to subtask 1.3, several directives such as 2006/42/EC on Machinery deal with the inclusion of safety issues and its effects on the environment (see also Figure 1-27, p. 126).

1.2.1.5 Machinery components related standards and technical specifications

Among the multitude of standards for the various components and systems of and related to machine tools those on motors are of specific interest:

IEC/EN 60034-30 harmonizes internationally the energy efficiency classes for motors, and is also referenced in Commission Regulation (EC) No 640/2009 on ecodesign requirements for electric motors (see 1.3.1)

IEC/TS 60034-31 defines the IE4 "super premium" efficiency class of synchronous and asynchronous motors, but solely as a technical specification, not as a standard, as the technology to achieve these efficiency levels is not yet fully established.

Figure 1-24 depicts the IE levels according to IEC/EN 60034-30 and IEC/TS 60034-31 for 4-pole motors.

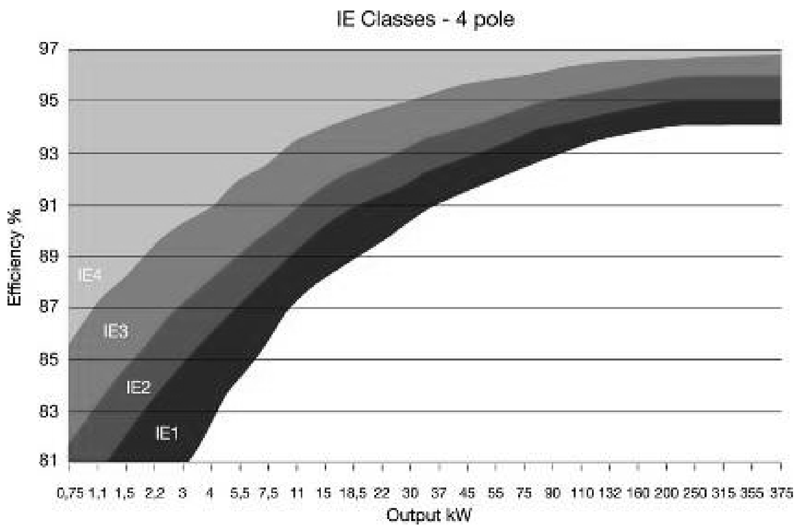

Figure 1-24: IE efficiency classes for 50 Hz 4-pole motors[133]

There is no standard yet for measuring energy efficiency of the combination of motor and variable speed drive, but in 2010 the EC gave a mandate to CEN, CENELEC and

133 Efficiency regulations for low voltage motors, ABB external presentation, July, 2010

ETSI for standardisation in the field of electric motors, covering procedures and methods of measuring the energy efficiency and associated characteristics for motors, including variable speed drives.

1.2.2 National standards

The national standard **NF E 01-005 – *Mechanical products – Ecodesign methodology* –** provides an ecodesign method for mechanical products, in particular for those manufactured by the mechanical engineering and metalworking industry, thus comprising machine tools as well. According to the standard, the environmental performance relies on the following seven environmental aspects: raw materials, manufacture, use, recyclability, hazardous substances, transportation, and packaging. This document is tailored to small and medium sized enterprises, aiming at a rising awareness for eco aspects in product design and on management level. It is based on five steps as set out below:

- Step 1: Determination of the environmental profile of the product: Determining the environmental profile is supported by a standardised environmental questionnaire. The seven environmental aspects will be ordered by its ecological relevancy.
- Step 2: Selection/ranking of design guidelines:[134] Deriving from the results from step 1, certain design guidelines (which are proposed by the standard) will be selected to improve the overall environmental performance of the product and ranked by the need for implementation. Exemplarily, if transport is the most important environmental aspect, a guideline could be the minimisation of product logistics.
- Step 3: Choice of environmental indicators: Referring to the design guidelines picked in step 2, appropriate indicators will be linked to each guideline. Exemplarily, to reduce product logistics, an indicator could be the number of kilometre involved from raw materials procurements up to putting on the market.
- Step 4: Monitoring of indicators: During the design phase, the adherence of ecodesign is assessed by the monitoring of the predefined indicators.

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[134] Note: Design guidelines of NF E 01-005 are basically the same as what we call improvement options.

- Step 5: Assessment – building on experience: Looking back on the completed process, the applied method for implementing ecodesign measures shall be analysed and assessed. In regard to further use and especially optimisation, a knowledge base should be created.

The standard furthermore identifies requirements for the effective implementation of the method. Besides several recommended office tools (e.g. software, analysing methods, etc.), it is assumed that the process is carried out by a multidisciplinary team with the support of all corporate functions (R&D, design office, purchasing, marketing, etc.) and management.

Although being on a generic level for mechanical products, this guide provides an overall improvement management system to implement strategies applicable for machine tools in terms of ecological efficiency. The process is carried by a structured methodology and numerous tools for environmental upgrading of products are provided. However, the provided design guidelines are very general and need to be more product-specific in regard to machine tools. To fill the gap between design guideline (e.g. minimising weight and volume of used materials) and indicator (e.g. weight in kg, volume in l or m^3), substantial product-specific technologies and techniques for implementation need to be provided. The assessment of the environmental profile cannot be used for the comparison of similar products. This is primarily due to the generic nature of the questionnaire, which partly relies on qualitative answers.

The German standard **DIN 33893-2:1997 – *Evaluation of the emissions of airborne hazardous substances – Part 2: Pollutant concentration parameter – Stationary woodworking machines* –** deals with the method of determining the concentration of wooden particles from the exhaust air. The procedure is specified for different types of woodworking machines, such as band saws, circular saw benches, planing machines, milling machines, and the like. DIN 33893 exclusively deals with the method of testing, meaning that within the context, no further (environmental) subjects are being addressed. Airborne wooden particles are of great importance regarding occupational safety but do not have great impacts on natural environment and ecosystems, thus they are of minor environmental relevance.

1.2.3 SEMI standards

The semiconductor industry, as mentioned above, published a couple of outstanding environmental standards, which shall be described briefly. As some machine tools are used within this industry, certain segments of the standards are of high relevancy.

- **SEMI S2-0703** – ***Environmental, Health, and Safety Guideline for Semiconductor Manufacturing Equipment*** – is the general guidance concerning prevention strategies for the semiconductor industry. According to the SEMI terminology, the expression equipment refers to "a specific piece of machinery, apparatus, process module, or device used to execute an operation". Users and suppliers are required to thoroughly consider environmental aspects and seek for improvement potential regarding reduction of resource consumption or the refurbishing or recycling of products.
- **SEMI S12-0298** – ***Guidelines for Equipment Decontamination*** – gives advice for decontaminating hazardous substances from certain products with the intention of further use. This way, the total waste accumulation and the exposure of hazardous substances to the environment shall be minimized.
- **SEMI S16-0600** – ***Guide for Semiconductor Manufacturing Equipment Design for Reduction of Environmental Impact at End of Life*** – is a guide providing specific help to minimize the environmental impact during the disposal of equipment from the semiconductor industry. The user is emboldened to take specific measures and to consider the environmental particularities of his product. Besides addressing end-of-life measures, the guide also provides assistance for selecting materials, designs and components for reusability and recyclability during construction phase.
- **SEMI S23-0311 –** ***Guide for Conservation of Energy, Utilities and Materials used by Semiconductor Manufacturing Equipment*** – is a guide intended to be a tool that can be used to analyse energy, utilities and materials conservation on semiconductor manufacturing equipment, but also defines (optional) requirements regarding power management. As the semiconductor industry is the one with the most stringent requirements regarding production accuracy, the requirements set in S23 might serve as a suitable blueprint for a much broader scope of machine tools.

1.2.4 Other standards

Siemens published a couple of company-specific standards dealing with environmental issues during product planning and development. As these standards are generally for company specific use, general validity is not provided.

- The Siemens specific standard **SN 36350-1** – ***Environmentally Compatible Products*** – deals with the inclusion of environmental issues during product planning and the development process. In accordance with ISO Guide 64 (see section 1.2.5), the life cycle thinking shall be comprised during these stages. As the scope of the guideline is used for company products only, whereas Siemens is in charge of producing components for machine tools, it is not exactly clear if machine tools as a whole shall be addressed or not.
- The **Environmental, Health and Safety (EHS) Guidelines** is a bundling of regulations which are meant to be incorporated into an existing management system. According to this guide and in regard to particular environmental loads, problems are initially identified and later confronted with certain measures to minimize the impact. Additionally, the guide imposes certain limits to air emissions and gives qualitative advice how to recognize improvement potentials. According to the industry specific guideline, the primary environmental issues deriving from the manufacturing of metal products are air emissions, wastewater, liquid wastes, and solid waste. The EHS Guidelines originate from an initiative by the World Bank Group, thus it has to be applied if members, which are almost every country in the world, of this group are involved in a project.
- Besides the general EHS Guideline, the **EHS Delivery Specifications (Machinery and installations)** should not remain unmentioned. The document provides an environmental check list for the supplier. Here, certain declarations concerning the environmental compatibility of the product have to be approved.

These measures imply a general sense of acceptance to involve environmental issues into the product planning and development process. The concepts are worth to keep in consideration when implementing machine tool related guidelines with ecological background.

1.2.5 Guidelines for the inclusion of environmental issues

There are several reports addressing the inclusion of environmental issues into the standardisation process. Although these reports are not standards themselves, they indicate the requirement for involving environmental issues. As none of the following guides are product specific (except for the IEC Guide, addressing only electro-technical products), machine tools can be considered being in the scope of the following reports.

- The **ISO Guide 64:2008**[135] – ***Guide for addressing environmental issues in product standards*** – supplies guidance how to comprise environmental issues into the composition of standards and intents to sensitize writers to environmental issues. As a general matter, the guide calls for the "use of life cycle thinking" and encourages the writer to relate to environmental topics and involve experts into the assessment of the standard. Based in the ISO 14000 series of standards, the guide provides numerous environmental criterions, such as energy and material input, water consumption, or emissions, which are ought to be considered during standardisation. Regarding the fact that no further product specifications are implied, all aspects remain important during the implementation of standards on machine tools.

- The **IEC Guide 109:1995** – ***Environmental aspects – Inclusion in electrotechnical product standards*** – is specifically dealing with the inclusion of environmental awareness for standardizing electronic products. In this regard, the report provides instructions for analyzing the environmental impact as well as implementing Ecodesign measures for a product. With respect to this study, the guide also relates to the defined product scope in 1.1., as machine tools generally consist of several electronic components, such as control systems and spindle drives. Furthermore, the IEC was the first committee to issue a guide addressing environmental aspects during product standardisation.

- **Guideline VDI 2243** – ***Recycling-oriented product development*** –, issued by the Association of German Engineers (Verein Deutscher Ingenieure - VDI), provides practical advice for developers and designers to comprise recyclability thinking during strategic, preliminary, and mass-production developing of technical products, covering machine tools as well. By dividing the development process into its core elements, the guide supplies detailed information, instructions and decision support. With the basic aim of optimizing material efficiency, the guide provides a mathematical pattern to calculate whether the component-based material is economically and ecologically recyclable and accordingly reusable or not. However, the guide considers that especially mass- and household products shall be addressed to comprise environmental features, such as appropriate dismantling properties, to their product design. These features are rather secondary in the field of machine tools.

[135] Note: The ISO Guide 64 is equivalent to the European standard CEN Guide 4.

- The **DIN Report 108** – ***Guide for the inclusion of environmental aspects in product standardisation and development*** – is a domestic guide generally based on findings from the ISO Guide 64 and IEC Guide 109. Besides comprising life cycle thinking, adequate labelling and classification of products according to environmental aspects, opportunities and restrictions deriving from the circular flow economy have to be taken into consideration as well. Thus, the DIN Report calls for minimizing mass flows during all stages of a product life cycle.

1.2.6 Standards in progress

Currently, the following standards are still in progress:

- **ISO/NP 14955 – *Environmental evaluation of machine tools***. This standard has been in development since December 2009, being motivated also by the Self-Regulatory Initiative of CECIMO, and is intended to describe and standardise an evaluation approach suitable to follow under the SRI, but being also applicable for the evaluation of metal working machine tools. Besides providing a list of improvement options for metal cutting and metal forming machine tools, the standard is structured in four parts, which are:
  - Part 1: Eco design methodology of machine tools
  - Part 2: Testing of energy consumption of modules
  - Part 3: Test pieces and parameters for metal cutting
  - Part 4: Test pieces and parameters for metal forming

  Part 1 provides a sound methodology to analyse the ecological profile of a machine tool. The user of the standard is instructed how to identify and specify functions and relate those to physical components. The analysis gives a hint to energy saving potentials.

  The system boundaries of the evaluated machine tool are depicted in Figure 1-25.

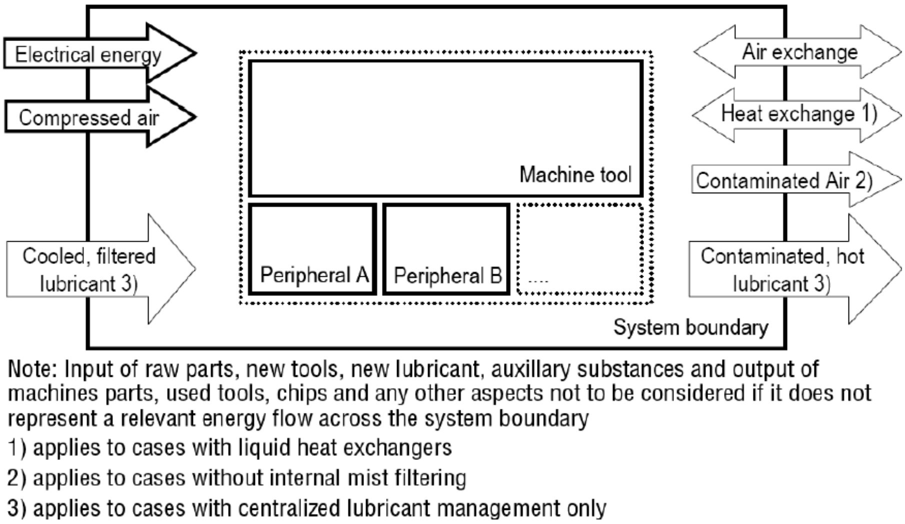

Figure 1-25: System boundaries of ISO/NP 14955 - Environmental evaluation of machine tools.[136]

Following the analysis on the current status, Annex A and B provide a list of improvements for components, the overall machine concept as well as guidance for the energy efficient use of machine tools.

The overall methodology for Part 1 can be summarized as shown in the following Figure 1-26:

136 HAGEMANN, D., *Status of ISO/TC39/WG12*, 1st stakeholder meeting "Machine tools and related machinery", Brussels, July 12, 2010, slide 10.

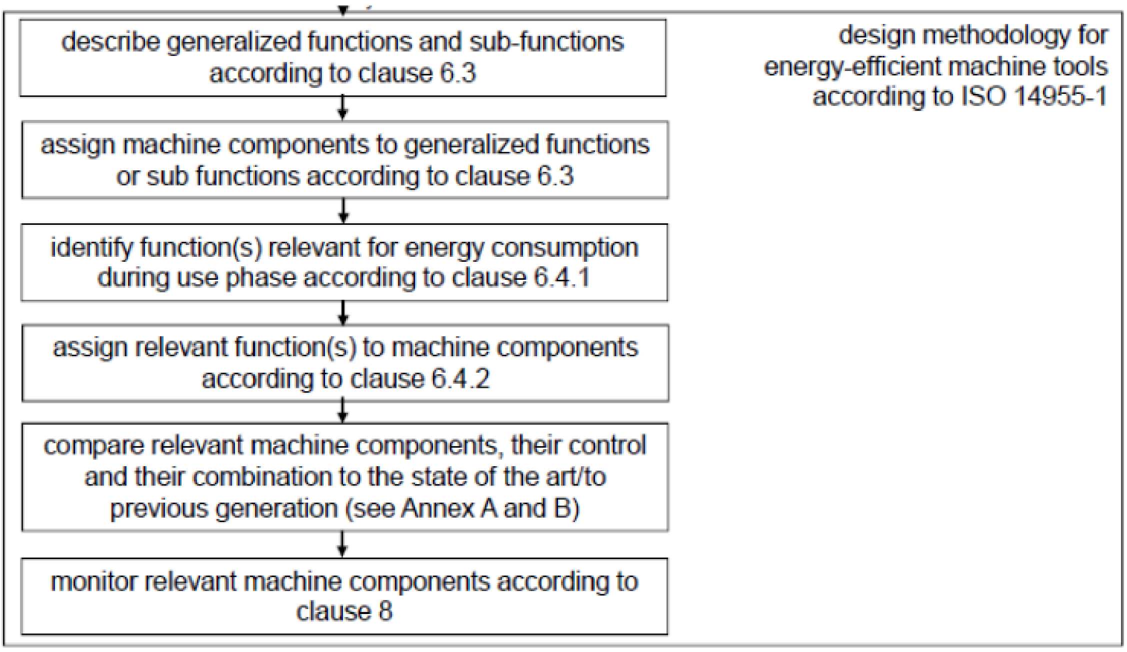

Figure 1-26: Design methodology for energy-efficient machine tools.[137]

- Besides general safety issues, **prEN ISO 28881:2010 – *Machine tools – Safety – Electro discharge machines*** – deals with the noise emission of electro discharge machines, being in a draft status currently.

1.2.7 Summary and conclusions – Gaps in standardisation

- **Metal working machine tools and woodworking machines**

As demonstrated above, there are very few standards primarily tackling environmental aspects, thus creating potential space for new standards for implementing measures. In the range of international standards, it should be pointed out that a sound methodology for noise measurement is provided specifically for metal working machine tools and woodworking machines, which could be used as a link for ecological based standardisation e.g. in terms of imposing limits for noise emission. Similar ecological enhancements are possible in regard to lubricants and lubrications as well, for which a technological foundation has already been established in standardisation for metal working

[137] ISO, ref. 41, p. 17.

machine tools. As far as ancillary equipment of woodworking machines are concerned, the interrelation of certain parameters and its effect on energy consumption has been discussed, which is an approach to arouse ecological awareness. However, internationally viewed, addressing environmental issues in the field of metal working machine tools and woodworking machines have not been subject to standardisation until now.

- **Welding, soldering, and brazing machines**

The environmental check list envisions environmental issues and proposes improvement options, comprising welding procedures, machines, and materials. However, besides the lack of specification in terms of quantitative standard values (e.g. as a fixed upper limit for particular emissions), the improvement options are lacking precise technological descriptions to enable easy application for the user.

- **Gaps in standardisation**

As pointed out above, no specific standardisation which could significantly influence the ecological performance is available for the product scope. Considering our environmental criterions as defined in task 1.1, need for regulation is identified in the field of power consumption, modes, and management as well as on consumption of lubricants, compressed air, water, and on waste. Substantial standards, such as those on noise measurement, reflect a sound basis for environmental upgrades. The aforementioned standard 8525:2008, for instance, demonstrates that the adherence to certain test conditions allows the comparability of specific machine tool features among each other; at least as far as noise emissions are concerned. Thus, defining appropriate test condition parameters to measure the energy consumption, if implementable, would be favourable to gain comparable results in regard to the energy profile of machines. For metal forming and cutting machine tools, such test conditions are currently in progress (ISO/NP 14955). Accordingly, improvement methodologies (namely NF E 01-005 or ISO/NP 14955) can be specified for further types of machinery besides metal working machine tools. Besides on operational level, no standardisation tailored to machine tools has been developed for any other product stage, notably manufacturing, distribution, and end-of-life. At this point, the significance for implementing standards may differ, e.g. as energy efficiency standards on an operational level assumingly dampers the environmental impact to a greater extent than distribution standards. This, however, solely provides a first idea how to integrate environmental issues in standardisation. Identifying the specific need for implementing measures will be investigated later in this study.

1.2.8 Matching standards and guidelines with life cycle stage

As pointed out above, it is evident that there are no standards explicitly addressing environmental aspects of machine tools yet.

There are few standards which can be brought into correlation with environmental relevancy of machine tools, such as ISO 5170 on lubrication systems and ISO 11204 et seqq. on noise test methods. Although based on technological features, ISO 5170 provides measures for the efficient (and correct, in correspondence with ISO 19378) use of lubricants, which is roughly in accordance with ecological requirements. Furthermore, ISO 19378 recommends certain lubricants for different machine tool applications.

Throughout the industry, a rising awareness regarding environmental issues during product life cycles is evident. This attitude is reflected by the guidelines on environmental thinking as described above. However, as they address the broad range of products, machine tools and their specifics are not addressed in detail.

There is no standard yet for machine tools regarding power consumption, or the definition of modes. The upcoming standard ISO/NP 14955 is likely to address these aspects due to the high relevancy of energy consumption for an environmental evaluation of machine tools.

Table 1-29 illustrates the relationship between standards and guidelines and the correspondent life cycle stage(s). Standards, for which the content is under development currently, are written in green (meaning the correlation to life cycle stages has to be preliminary). Reports, such as ISO Guide 64, are written in italic.

Table 1-29 also lists the current gaps in standardisation of machine tools with respect to some major environmental aspects. In case this Product Group Study unveils a high relevancy of these (and other) environmental aspects, it might be advisable to initiate standardisation projects accordingly.

Table 1-29: Allocation of standards to its appropriate life cycle stage

Manufacture / Design	Distribution / Redistribution	Product Usage	End-of-Life
• ***DIN Report 108*** *– Guide for the inclusion of environmental aspects in product standardisation and development* • ***IEC Guide 109:1995*** *– Environmental aspects –*	• ***DIN Report 108*** *– Guide for the inclusion of environmental aspects in product standardisation and development* • ***IEC Guide 109:1995*** *– Environmental aspects –*	• ***DIN Report 108*** *– Guide for the inclusion of environmental aspects in product standardisation and development* • *Environmental, Health and Safety (**EHS**)*	• ***DIN Report 108*** *– Guide for the inclusion of environmental aspects in product standardisation and development* • ***IEC Guide 109:1995*** *– Environmental aspects –*

Manufacture / Design	Distribution / Redistribution	Product Usage	End-of-Life
Inclusion in electrotechnical product standards • ***ISO Guide 64:2008*** *– Guide for addressing environmental issues in product standards* • **NF E 01-005** – Mechanical products – Ecodesign methodology • ***SEMI S16-0600*** – *Guide for Semiconductor Manufacturing Equipment Design for Reduction of Environmental Impact at End of Life* • ***SEMI S2-0703*** – *Environmental, Health, and Safety Guideline for Semiconductor Manufacturing Equipment* • **SN 36350-1** – Environmentally Compatible Products • ***VDI 2243*** – *Recycling-oriented product development* Metal working machine tools: • **ISO/NP 14955** – Environmental evaluation of machine tools	*Inclusion in electrotechnical product standards* • ***ISO Guide 64:2008*** *– Guide for addressing environmental issues in product standards* • **NF E 01-005** - Mechanical products – Ecodesign methodology Metal working machine tools: • **ISO/NP 14955** – Environmental evaluation of machine tools	*Guidelines* • ***IEC Guide 109:1995*** *– Environmental aspects – Inclusion in electrotechnical product standards* • **ISO 11204:1997** – Noise emitted by machinery and equipment • ***ISO Guide 64:2008*** – *Guide for addressing environmental issues in product standards* • **NF E 01-005** – Mechanical products – Ecodesign methodology Metal working machine tools: • **ISO 19378:2003** – Machine-tool lubricants – Categories and specifications • **ISO 230:2009** – Test code for machine tools – Determination of vibration levels • **ISO 5170:1977** – Lubrication systems for machine tools • **ISO 8525:2008** – Airborne noise emitted by machine tools – Operating conditions for metal-cutting machineries, • **ISO/NP 14955** – Environmental evaluation of machine tools • **prEN ISO 28881:2010** – Machine tools – Safety – Electro discharge machines Welding, soldering, and brazing machines: • **DIN EN 14717:2005 –** Welding and allied processes – Environmental check list	*Inclusion in electrotechnical product standards* • ***ISO Guide 64:2008*** *– Guide for addressing environmental issues in product standards* • **NF E 01-005** – Mechanical products – Ecodesign methodology • ***SEMI S12-0298*** – *Guidelines for Equipment Decontamination* • ***SEMI S16-0600*** – *Guide for Semiconductor Manufacturing Equipment Design for Reduction of Environmental Impact at End of Life* Metal working machine tools: • **ISO/NP 14955** – Environmental evaluation of machine tools

Manufacture / Design	Distribution / Redistribution	Product Usage	End-of-Life
		Woodworking machines: • **DIN 33893-2:1997** – Evaluation of the emissions of airborne hazardous substances – Par 2: Pollutant concentration parameter – Stationary woodworking machines • **ISO 7960:1995** – Airborne noise emitted by machine tools – Operating conditions for woodworking machines	
Major environmental aspects not yet covered comprehensively by approved standards for machine tools specifically			
• Eco-design process • Marking / labelling of materials / components (e.g. identification of hazardous substances)		• Power consumption • Power modes • Power management • Consumption of lubricants • Consumption of compressed air • Process waste generation, including yield losses	

The table on the following pages provides an overview of existing standards per environmental aspect for each sub-category of machine tools and separately for the main machine modules. “Not applicable” is stated, where a certain environmental aspect is not linked to a machine or module, “none” marks potentially relevant aspects, for which there is no dedicated standard yet.

Table 1-30: Allocation of standards per machinery type and modules to environmental aspects

	Energy consumption / efficiency	Consumable and media consumption / efficiency	Water consumption	Noise	Airborne Emissions	System design guidance / environmental checklists	Refurbishment / retrofitting / disposal
Machinery / equipment							
Metal working machine tools	**ISO/NP 14955 –** Environmental evaluation of machine tools (in progress)	**ISO 19378:2003** – Lubricants, industrial oils and related products (class L) – Machine-tool lubricants – Categories and specifications (no direct addressing of environmental issues) **ISO 5170:1977 –** Lubrication systems for machine tools **ISO/NP 14955 –** Environmental evaluation of machine tools (in progress)	**ISO/NP 14955 –** Environmental evaluation of machine tools (in progress)	**ISO 11204:1997 –** Noise emitted by machinery and equipment – Measurement of emission sound pressure levels at a work station and at other specified positions – Method requiring environmental corrections (measurement only) **ISO 230:2009 –** Test code for machine tools – Determination of vibration levels (measurement only) **ISO 8525:2008** – Airborne noise emitted by machine tools – Operating conditions for metal-cutting machineries (measurement only)	**none**	**NF E 01-005** – Mechanical products – Ecodesign methodology (generic, not tailored to metal working machine tools) **ISO/NP 14955 –** Environmental evaluation of machine tools (in progress)	**ISO/NP 14955** – Environmental evaluation of machine tools (in progress)
Wood working machine	**DIN EN 12779:2004+A1:2009** – Safe-	**DIN EN 12779:2004+A1:2009** – Safety of	**none**	**ISO 7960:1995 –** Airborne noise emitted by machine tools	**DIN EN 12779:2004+A1:2009** – Safety of	**DIN EN 12779:2004+A1:2009** – Safety of wood-	**none**

	Energy consumption / efficiency	Consumable and media consumption / efficiency	Water consumption	Noise	Airborne Emissions	System design guidance / environmental checklists	Refurbishment / retrofitting / disposal
tools	ty of woodworking machines – Chip and dust extraction with fixed installation – Safety related performances and requirements (relating the energy consumption to specific parameters)	woodworking machines – Chip and dust extraction with fixed installation – Safety related performances and requirements		– Operating conditions for woodworking machines (measurement only) **DIN EN 12779:2004+A1:2009** – Safety of woodworking machines – Chip and dust extraction with fixed installation – Safety related performances and requirements	woodworking machines – Chip and dust extraction with fixed installation – Safety related performances and requirements **DIN 33893-2:1997** – Evaluation of the emissions of airborne hazardous substances – Part 2: Pollutant concentration parameter – Stationary woodworking machines	working machines – Chip and dust extraction with fixed installation – Safety related performances and requirements (system design guidance only) **NF E 01-005 –** Mechanical products – Ecodesign methodology (generic, not tailored to woodworking machine tools)	
Welding equipment	**DIN EN 14717:2005 –** Welding and allied processes – Environmental check list	**DIN EN 14717:2005** – Welding and allied processes – Environmental check list	**DIN EN 14717:2005 –** Welding and allied processes – Environmental check list	**DIN EN 14717:2005** – Welding and allied processes – Environmental check list	**DIN EN 14717:2005 –** Welding and allied processes – Environmental check list	**DIN EN 14717:2005** – Welding and allied processes – Environmental check list (environmental check list only) **NF E 01-005 –** Mechanical products – Ecodesign methodology (generic, not tailored to welding equipment)	**DIN EN 14717:2005 –** Welding and allied processes – Environmental check list (disposal of process media only)

	Energy consumption / efficiency	Consumable and media consumption / efficiency	Water consumption	Noise	Airborne Emissions	System design guidance / environmental checklists	Refurbishment / retrofitting / disposal
Other related machinery	**EUROMAP 60 -** Injection Moulding Machines – Determination of Specific Machine Related Energy Consumption	**none**	**none**	**none**	**none**	**NF E 01-005 –** Mechanical products – Ecodesign methodology (generic) **SEMI S2-0703 –** Environmental, Health, and Safety Guideline for Semiconductor Manufacturing Equipment **Guideline VDI** 2243 – Recycling-oriented product development (generic) **DIN Report 108 –** Guide for the inclusion of environmental aspects in product standardisation and development	**SEMI S2-0703** – Environmental, Health, and Safety Guideline for Semiconductor Manufacturing Equipment **SEMI S12**-0298 – Guidelines for Equipment Decontamination (semiconductor equipment) **SEMI S16**-0600 – Guide for Semiconductor Manufacturing Equipment Design for Reduction of Environmental Impact at End of Life **SN 36350-1 –** Environmentally Compatible Products (generic, company specific) **Guideline VDI 2243 –** Recycling-oriented

	Energy consumption / efficiency	Consumable and media consumption / efficiency	Water consumption	Noise	Airborne Emissions	System design guidance / environmental checklists	Refurbishment / retrofitting / disposal
							product development
Frame	**not applicable**	**not applicable**	**not applicable**	**none**	**not applicable**	**none**	**none**
Guides and bearings	**none**	**none**	**not applicable**	**none**	**not applicable**	**none**	**none**
Main and feed drives	**IEC/EN 60034-30** - Rotating electrical machines - Part 30: Efficiency classes of single-speed, three-phase, cage-induction motors (IE-code) **IEC/TS 60034-31** - Rotating electrical machines - Part 31: Selection of energy-efficient motors including variable speed applications - Application guide	**none**	**none**	**none**	**not applicable**	**none**	**none**
Control	**none**	**Not applicable**	**Not applicable**	**Not applicable**	**Not applicable**	**none**	**none**

	Energy consumption / efficiency	Consumable and media consumption / efficiency	Water consumption	Noise	Airborne Emissions	System design guidance / environmental checklists	Refurbishment / retrofitting / disposal
devices							
Fluidic systems (hydraulic, pneumatic)	**ISO 7183:2007 -** Compressed-air dryers -- Specifications and testing (pneumatic dryers measurement)	**ISO 8573** - Compressed air - Part 1: Contaminants and purity classes (quality requirements pressurized air) **ISO 7183:2007 -** Compressed-air dryers -- Specifications and testing (pneumatic dryers measurement)	**not applicable**	**ISO 7183:2007 -** Compressed-air dryers -- Specifications and testing (pneumatic dryers measurement) **Pneurop PN8NTCI** - Noise test code for compressors	**none**	**ISO 8010, ISO 8011, ISO 8012** - Compressors for the process industry -- Screw and related types -- Specifications and data sheets for their design and construction	**none**
Cooling / cooling lubricants units	**None** (for metal working, see above)	**None**	**none**	**none**	**none**	**none**	**none**
Process media supply	**none**	**none**	**none**	**none**	**none**	**none**	**none**
Power supply	**none**	**none**	**not applicable**	**none**	**none**	**none**	**none**

1.3 Existing legislation

This task identifies the relevant legislation and voluntary initiatives for machine tools at EU level, Member State level, and in countries outside Europe.

1.3.1 Legislation and Agreements at European Community level

There are a couple of European Directives that apply to electrical and electronic equipment with respect to health, safety and performance:

- **Directive 2001/95/EC on general product safety (GPSD)**. This directive is on consumer goods and therefore not relevant for this study.
- The **Low Voltage Directive (LVD) 2006/95/EG** lays down the requirements covering all health and safety risks of electrical equipment operating within certain voltage ranges. The LVD in principle covers machine tools[138], but the Guide to application of Directive 2006/42/EC[139] clarifies, that machinery with an electrical supply within the voltage limits of the Low Voltage Directive (i.e. between 50 and 1000 V for alternating current or between 75 and 1500 V for direct current; and not listed among the categories of low voltage electrical and electronic machinery that are excluded from the scope of the Machinery Directive) must fulfil the safety objectives of the LVD.
- The **Electromagnetic Compatibility (EMC) Directive 2004/108/EG** lays down requirements in order to prevent electrical and electronic equipment from generating or being affected by electromagnetic disturbances. The EMC directive requires inter alia compliance with EN61000-3-2, which defines power factor, i.e. harmonic current injection requirements. Machine tools have to comply with the EMC directive.
- The **Pressure Equipment Directive 97/23/EG** is relevant for those machine tools, i.e. parts thereof, operating with fluids and compressed air under certain circumstances, meaning at high pressures – rather untypical for most, but not all machine tools.

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[138] See: Verein Deutscher Werkzeugmaschinenfabriken: Anwendung der neuen EG-Maschinenrichtlinie 2006/42/EG im Werkzeugmaschinenbau, June 2007

[139] Fraser, I. (editor): Guide to application of Directive 2006/42/EC, 1st Edition, December 2009, DG Enterprise and Industry

- The **Directive concerning equipment and protective systems intended for use in potentially explosive atmospheres (ATEX) 94/9/EG** is only relevant for those machine tools intended to operate in certain production environments, e.g. use in the chemical industry could be affected.
- **Directive 2006/42/EC on machinery** is the main European legislation affecting machine tools and setting a couple of dedicated requirements for a broad spectrum of machines and equipment.

All these Directives are based on the principles of the so-called "New Approach", prescribing essential requirements, the voluntary use of standards, and conformity assessment procedures to be applied in order to apply the CE marking.

The Machinery Directive explicitly tackles also some aspects, which are intended to limit environmental impacts (including health impacts on workers), i.e.

- Safety integration
- Materials and products and related design measures must not endanger persons' safety or health
- Airborne noise (and other emissions, such as vibrations, radiation) has to be minimised
- Emissions of hazardous materials and substances have to be reduced through design and construction

On the other hand, some requirements of the Machinery Directive are clearly a compromise between the environment and safety, giving preference to safety, e.g. the requirement of sufficient lighting within the machinery.

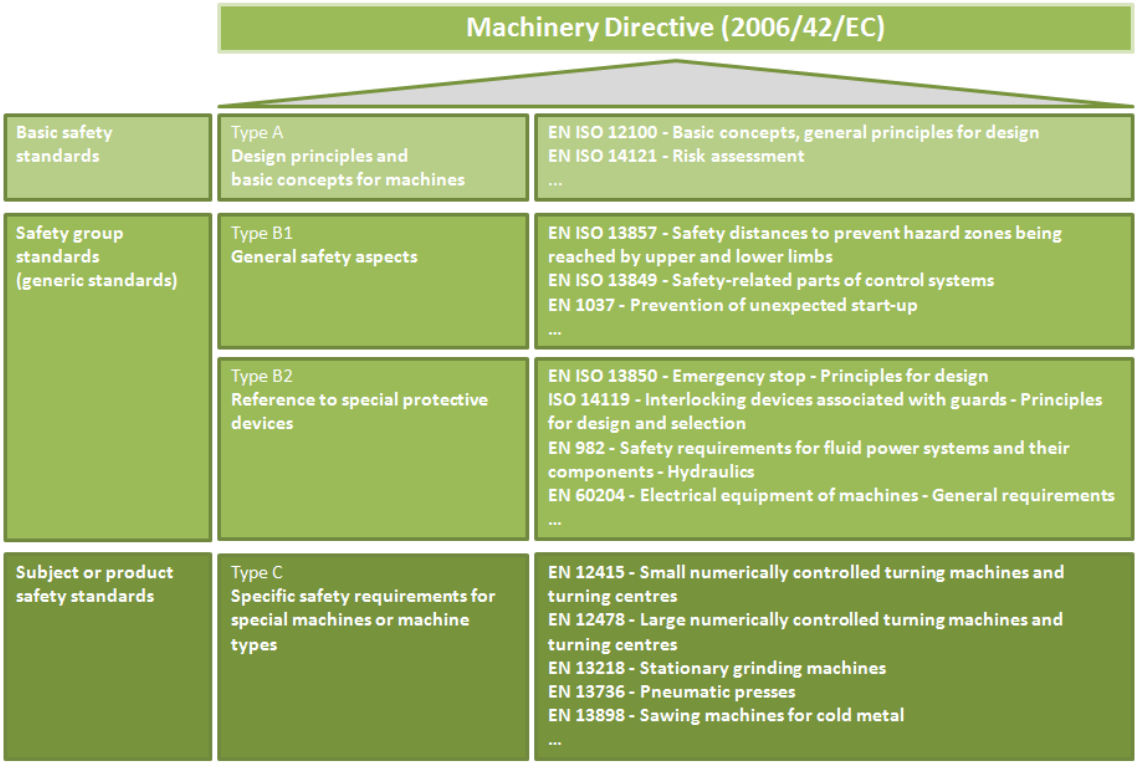

Figure 1-27: Correlation of the Machinery Directive 2006/42/EC with safety norms

When investigating environmental improvement potentials in tasks 5 and 6 of this study, the requirements set by the machinery directive have to be observed. For details and interpretation of the Machinery Directive see the EC's Guide to Application of Directive 2006/42/EC - 1st Edition - December 2009[140].

With regards to the product categories concerned by the study, additional European Union legislation with particular environmental requirements comprises the WEEE/RoHS directive:

- **Directive 2002/96/EC on waste electrical and electronic equipment (WEEE)**
- **Directive 2002/95/EC on the restriction of the use of certain hazardous substances in electrical and electronic equipment (RoHS)**

140 Fraser, I. (editor): Guide to application of Directive 2006/42/EC, 1st Edition, December 2009, DG Enterprise and Industry , http://ec.europa.eu/enterprise/sectors/mechanical/documents/guidance/machinery/index_en.htm

The FAQ document of the European Commission defines “large-scale stationary industrial tools”, which are exempted from RoHS and WEEE as follows:

“machines or systems, consisting of a combination of equipment, systems, finished products and/or components, each of which is designed to be used in industry only, permanently fixed and installed by professionals at a given place in an industrial machinery or in an industrial building to perform a specific task. Not intended to be placed on the market as a single functional or commercial unit.“

To our understanding, most machine tools meet the first sentence of this definition, but as they are intended to be placed on the market as a single commercial unit[141] (with the exception of larger production lines consisting of machine tools and other machinery, which are customized for such kind of interlinked installation[142]). Consequently, following this argumentation machine tools are in the scope of RoHS and WEEE as “Electrical and electronic tools” (no. 6, Annex I A WEEE), including the sub-category “Equipment for turning, milling, sanding, grinding, sawing, cutting, shearing, drilling, making holes, punching, folding, bending or similar processing of wood, metal and other materials”. Exempted from RoHS, but not WEEE are “Monitoring and control instruments” (no. 9), as long as they are independent products used in e.g. an industrial environment. Integrated monitoring and control instruments of a machine tool are part of the machine tool and therefore are subjected to the same regulations under RoHS and WEEE as the machine tool itself.

Some manufacturers of machine tools share the point of view that machine tools do not fall under RoHS and WEEE[143]. According to the German Federal Ministry for the Environment some machine tools fall under the exemption, others do not: Exempted large-scale stationary industrial tools are “e.g. industrial robots, or immobile machinery, such as a stationary saw in a carpenter’s shop, contrary to a mobile circular saw to be used

141 Otherwise also the PRODCOM statistic, which refers to individual units sold, would not be applicable.

142 But even these types of installations are covered in “units” by PRODCOM, see e.g. PRODCOM 28411270 Multi-station transfer machines for working metal

143 See e.g. Kugler: RoHS Konformität – Handlungshilfe zur Kommunikation entlang der Lieferkette über die Einhaltung stoffbezogener Anforderungen aus der Richtlinie 2002/95/EG (RoHS), http://kugler-relaunch.workonweb.de/index.php?action=download&id=320; and: LEAD: Neues ElektroG – was bedeutet das für LEAD Produkte? http://www.lead-online.com/catalog/pdf/Datenblatt_ElektroG_LEAD.pdf; notice, that Kugler and LEAD despite these statements claimed already years ago to apply the relevant substance bans to their products and components

on construction sites, or a stationary drilling machine tool contrary to a handheld drilling machine."[144]

As far as machine tools are concerned, the scope is not changed in the European Commission's recast proposal of WEEE (COM/2008/0810 final) and RoHS (COM/2008/0809 final), but the Committee on the Environment, Public Health and Food Safety of the European Parliament formulated amendments[145] to the recast proposal, explicitly deleting the phrase "(with the exception of large-scale stationary industrial tools)", and consequently, if this version is adopted machine tools will be covered unambiguously.

RoHS restricts the use of the following substances: Lead, mercury, cadmium, chromium-IV, PBB and PBDE. Exemptions from this ban for certain applications apply, such as lead up to a certain level in steel, aluminium and copper alloys to allow for a better workability of these alloys, which is relevant for certain machine elements.

Regarding the WEEE directive, machine tools in their majority count as "WEEE from users other than private households", or in other words: business-to-business e-waste. For such kind of WEEE the producer is responsible for financing the costs for the collection, treatment, recovery and environmentally sound disposal. Actually, machine tool manufacturers have to offer a takeback of obsolete equipment, conditions can be fixed in any sales contract. An IPTS study in 2006 stated, that "Those companies operating in B2B markets do not regard the Directive as impacting upon pricing strategy as implementation of the Directive remains less developed in the B2B area, and many companies already manage their own take-back systems due to the specific high-value nature of B2B used goods."[146] This high-value nature is in particular true for the machine tools market as machine tools are made of valuable metals and alloys and typically do not contain very hazardous substance, which would otherwise add to disposal costs significantly.

There is one EuP implementing measure in place already which tackles a certain type of components of machine tools, the **Commission Regulation (EC) No 640/2009 on ecodesign requirements for electric motors**.

[144] Federal Ministry for the Environment, Nature Conservation and Nuclear Safety: Elektro- und Elektronikgerätegesetz - Hinweise zum Anwendungsbereich des ElektroG, June 24, 2005

[145] 2008/0240(COD), 14.12.2009

[146] Savage, M.: Implementation of the Waste Electric and Electronic Equipment Directive in the EU, DG JRC, 2006, p.30

The scope of this implementing measure covers “electric single speed, three-phase 50 Hz or 50/60 Hz, squirrel cage induction motor that:

- has 2 to 6 poles,
- has a rated voltage of U_N up to 1 000 V,
- has a rated output P_N between 0,75 kW and 375 kW,
- is rated on the basis of continuous duty operation.”

Such kind of motors are typically used in industrial applications for compressors, pumps etc. From 1 January 2015 motors with a rated output of 7.5-375 kW shall be equipped with a variable speed drive and from 1 January 2017 this requirement is extended to motors in the 0.75-7.5 kW range. Three-phase AC induction motors covered by this implementing measure represent 83.5% of the total European motor market, with a growing market share. The rest of the motor market is represented by various types of DC motors, single phase induction motors, universal and synchronous motors, which are often used in particular applications; many of them are sold in small quantities[147]. However, synchronous motors are used occasionally in machine tools, and also induction motors with a power rating beyond 375 kW are on the market for machine tools specifically[148], which means that Commission Regulation 640/2009 does not cover the full spectrum of motors used in machine tools.

The **EuP implementing measure for fluorescent lamps without integrated ballast, for high intensity discharge lamps, and for ballasts and luminaires able to operate such lamps (245/2009/EC)** explicitly exempts from the scope lamps and luminaires used in products falling under the machinery directive.

The **EuP implementing measure on no-load condition electric power consumption and average active efficiency of external power supplies (278/2009/EC)** covers explicitly only power supplies for household and office appliances, not industrial applications. However, it is worthwhile noticing that in industrial applications there are similar power supply units in use (mainly DIN rail power supplies). Commission Regula-

147 European Commission: Full Impact Assessment - Accompanying document to the Commission Regulation implementing Directive 2005/32/EC of the European Parliament and of the Council with regard to ecodesign requirements for electric motors, SEC(2009) 1013 final, July 22, 2009

148 See e.g.: Siemens: servomotors brochure, http://www.sea.siemens.com/us/internet-dms/Internet/MachineToolsComm/General/Docs/servomotors.pdf

tion 278/2009 defines maximum no-load power consumption and minimum average efficiency.

The **EuP implementing measure on computers and monitors** (under development currently) might cover also control computers and monitors of industrial equipment, but as of December 2011 no related implementing measure has been adopted.

Similarly, **Energy Star** requirements are in place for computers and monitors. As control units of CNC machines (although not for peripheral devices, such as monitoring and control sensors etc.) technically speaking similar to Personal Computers, same energy requirements might be applicable, but it is important also to recognise the specifics of industrial PCs[149].

Within the industry there is no voluntary agreement yet, but CECIMO initiated a **Self-Regulation Initiative** (SRI) in 2009, which has been presented to the EuP Consultation Forum as a possible alternative to any eco-design implementing measure. CECIMO informs about the progress of this SRI at http://www.cecimo.eu/index.php/ecodesign-eup/selfregulation.html. As CECIMO members are from the metal-working machine tools industry, this SRI in its current status of discussion is meant to address metal-working machine tools only. However, the general approach proposed by CECIMO might be transferrable to other kinds of machine tools as well.

As machine tools are used in industrial environments there is production / company related environmental legislation, which does not address machine tools specifically, but nevertheless might be relevant for the operation of machine tools. Such legislation is for example

- **Regulation 1221/2009 on the voluntary participation by organisations in a Community eco-management and audit scheme (EMAS)**, setting the requirements of a voluntary environmental management system, which in case of a metal or wood working enterprise typically requires setting of environmental improvement targets for the operation of machine tools as a core activity of the company.

149 Industrial PCs are normally exceptionally robustly constructed and have a considerably higher level of failsafe design due to environmental influences or electromagnetic interference. As they are operated frequently in harsh environment they need to be protected against dust, humidity etc., which might require adapted fan concepts, filters or specific housings. Similarly, production environments sensitive to vibration might require fan-less designs. All this has an impact also on computer power consumption.

1.3.2 Legislation at Member State level

On member state level the EU directives are implemented by means of national legislation. Partly there is further guidance without legislative order set by other players, such as the employers' liability insurance associations in Germany ("Berufsgenossenschaften"), e.g.:

- BGI/GUV-I 719 - Brand- und Explosionsschutz an Werkzeugmaschinen
- BGI 5003 - Maschinen der Zerspanung - Berufsgenossenschaftliche Informationen für Sicherheit und Gesundheit bei der Arbeit

A number of further information and advice instructions are provided by employers' liability insurance associations oriented to Directive 2006/42/EC on machinery.

Some legislation on member states level covers machine tools under certain conditions: The German **Verordnung zum Umgang mit wassergefährdenden Stoffen (VUmwS)**, currently under development, defines requirements for machinery and installations which contain substances, which are hazardous for the aquatic environment, i.e. including hydraulic fluids and cooling lubricants. Safe guarding measures are required in case certain minimum amount and/or level of hazardousness of contained substances are exceeded.

The Czech eco-label covers **hydraulic liquids**[150], basically requiring a certain level of biodegradability and setting requirements for low ecotoxicity.

1.3.3 Third Country Legislation

There is no known environmental third country legislation tackling only machine tools, but a couple of regulations regarding general production EHS issues.

In **Japan** the Law concerning the Rational Use of Energy[151] implements a comprehensive framework on energy related aspects, including measures for equipment, but these measures target at consumer products including vehicles, not machine tools or other industrial equipment. For factories standards are fixed for a "rational use of energy": For motors and power factors of certain type (and size) of industrial equipment target values are fixed,

[150] Technická směrnice, č. 15 - 2009

[151] See: The Energy Conservation Center, Japan: Japan Energy Conservation Handbook 2008

The target value of power factor at the power receiving end is 95% or more and it is applied to the equipment listed below (those devices relevant for the machine tools market highlighted in bold). Meeting the target value has to be ensured by management the system of the factory.

Table 1-31: Equipment subject to a target value of a power factor of 95% under the Japanese Energy Law

Equipment name	Capacity (kW)
Cage-type induction motor	**more than 75**
Coil-type induction motor	**more than 100**
Induction furnace	more than 50
Vacuum melting furnace	more than 50
Induction heater	more than 50
Arc furnace	-
Flash butt welder (excluding portable type)	**more than 10**
Arc welder (excluding portable type)	**more than 10**
Rectifier	more than 10,000

Japan also introduced a taxation system for promoting investments in the reform of energy supply and demand structures (Taxation System for the Energy Reform). This system entitles a purchaser of any energy efficient equipment to receive either a tax credit that is equivalent to 7% of the reference purchase value or a special depreciation that is not greater than 30% of the reference purchase value, in addition to normal depreciation of the equipment. Among other types of equipment this regulation explicitly covers also “high-efficient composite machine tools”[152].

In **China** the Law on Conserving Energy empowers the administrative department for energy conservation under the State Council to define a catalogue of highly energy-consuming products and equipment to be eliminated (Art. 17), but no machine tools are covered by this catalogue currently. Furthermore, the law sets requirements for so called energy-using units (Art. 20-31), namely energy consumption ratios per unit, but the definition of energy-using units in terms of energy consumption is far beyond the typical range of machine tools, thus not relevant for the scope of this study. Similarly to the European legislation, there are safety measures in place for machine tools (or machinery in general) in numerous countries, to name only a few:

152 The Energy Conservation Center: Questions& Answers for Application of the Taxation System for Promoting Investment in the Reform of the Energy Supply and demand Structures, Japan 2009

- United States of America: federal regulations implement standards of the Occupational Safety and Health Administration (OSHA). OSHA Standard 29 CFR[153] 1910, Subpart O covers woodworking machinery, abrasive wheel machinery, and mechanical power presses[154]. For woodworking machinery these regulations establish standards and tolerance levels for sawdust, filings, and fumes in the workplace, and cover aspects of machine guarding and personal safety. Workplace safety regulations are often enforced at the state level by state occupational health and safety agencies and by local fire departments. The California Air Resources Board (CARB) has imposed regulations on formaldehyde exposure from composite wood products containing urea-formaldehyde resins which affect machinery operators in woodshops and saw mills. The machinery technology is affected by this legislation as additional equipment to trap residues and wood dust is required.[155]
- Canada, British Columbia: under the Workers Compensation Act, Occupational Health and Safety Regulation are adopted, explicitly setting OHS requirements for power presses, brake presses and shears regarding point of operation safeguarding, design, construction, and reliability of operating controls
- Malaysia: P.U.(A) 113/83 Factories and Machinery (Fencing of Machinery and Safety) Regulation 1970 (revised - 1983); Part IV – Driven Machinery, Regulation 37. Machine tools

There are very few eco-labels in place for industrial equipment, such as the labelling of low-noise construction machinery under the Korean National eco-labelling scheme (KOECO), but none for machine tools. Nevertheless, there is one eco-label of relevancy under the KOECO scheme, namely that on **hydraulic fluids**[156] with the requirement "biodegradable" according to a certain minimum level of biodegradation following any of the test methods listed in the label criteria.

The Thai Green Label Scheme covers **energy-efficient motors** (three-phase induction motors which have a rated output and a voltage not exceeding 375 kW or 500 horse

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[153] Code of Federal Regulations

[154] http://www.osha.gov/SLTC/machineguarding/standards.html

[155] Abrahams, E.: Woodworking Machinery – Industry Assessment, International Trade Administration, USA; February 2009, http://www.trade.gov/mas/manufacturing/OAAI/Assess_WoodWorking_Machinery.asp

[156] EL601-1993/5/2005-68

power and 1,000 volts, respectively)[157]. The label criteria date back to 1998 and in the meantime the EuP implementing measure for motors (see above) are adopted: Depending on the number of poles and rated output power for certain motor types the EuP IE2 efficiency level is more ambitious than the Thai eco-label criteria, whereas for other motor types (in particular with 6 poles at rated output power below 5.5 kW) the Thai eco-label criteria require an efficiency exceeding the IE3 efficiency level.

Since 2010 a regulation is in place in the US for **small motors**, which is basically relevant for auxiliary motors in machine tools, and for smaller machine tools (light-stationary machine tools in particular):

- US Department of Energy: 10 CFR Part 431 - Energy Conservation Program: Energy Conservation Standards for Small Electric Motors[158]

Minimum efficiency requirements being effective from March 2015 are listed in Table 1-32, but it should be noted, that motors in the US are designed to operate at 110 V (single-phase) and 60 Hz. The standard referenced in the regulation is IEEE Standard 112–2004 (Test Method A and Test Method B), IEEE Standard 114–2001, and Canadian Standards Association Standard C747–94 as test procedures to measure energy efficiency small electric motors.

Table 1-32: Minimum average full-load efficiencies for small motors under the US regulation

Motor output power	Six poles	Four poles	Two poles
STANDARD LEVELS FOR POLYPHASE SMALL ELECTRIC MOTOR			
0.25 Hp/0.18 kW	67.5	69.5	65.6
0.33 Hp/0.25 kW	71.4	73.4	69.5
0.5 Hp/0.37 kW	75.3	78.2	73.4
0.75 Hp/0.55 kW	81.7	81.1	76.8
1 Hp/0.75 kW	82.5	83.5	77.0
1.5 Hp/1.1 kW	83.8	86.5	84.0
2 Hp/1.5 kW	N/A	86.5	85.5
3 Hp/2.2 kW	N/A	86.9	85.5
STANDARD LEVELS FOR CAPACITOR-START INDUCTION-RUN AND CAPACITOR-START CAPACITOR-RUN SMALL ELECTRIC MOTORS			
0.25 Hp/0.18 kW	62.2	68.5	66.6
0.33 Hp/0.25 kW	66.6	72.4	70.5
0.5 Hp/0.37 kW	76.2	76.2	72.4

157 TGL-15-98 (07-10-98)

158 Docket Number EERE–2007–BT–STD–0007, Federal Register / Vol. 75, No. 45 / Tuesday, March 9, 2010

0.75 Hp/0.55 kW	80.2	81.8	76.2
1 Hp/0.75 kW	81.1	82.6	80.4
1.5 Hp/1.1 kW	N/A	83.8	81.5
2 Hp/1.5 kW	N/A	84.5	82.9
3 Hp/2.2 kW	N/A	N/A	84.1

1.3.4 International Activities

The international EPD®system is based on a hierarchic approach following among others ISO 9001 (Quality management systems), ISO 14001 (Environmental management systems), ISO 14040 (LCA - Principles and procedures), ISO 14044 (LCA - Requirements and guidelines), ISO 14025 (Type III environmental declarations) upon which the General Programme Instructions are based, as well as instructions for developing Product Category Rules (PCR).

GNC Manufacturing

EPD®

Results from the cradle to the client gate

UPSTREAM (1 unit) maximum values		RECONF12	RECONF12 + ACS1	RECONF12 + ACS2	RECONF15, 16	RECONF15, 16 + ACS1	RECONF15, 16 + ACS2	RECONF15, 16 + ACS3
GLOBAL WARMING	kg CO_{2eq}	45 000	47 800	46 200	50 000	52 800	51 200	50 100
OZONE DEPLETION	kg CFC-11_{eq}	197	197	197	197	197	197	197
PHOTOCHEMICAL OXIDATION	kg $C2H4_{eq}$	29.0	30.8	29.8	32.3	34.2	33.1	32.4
ACIDIFICATION	kg $SO2_{eq}$	121	207	194	217	235	222	218
EUTROPHICATION	kg $PO4_{eq}$	27.7	30.6	28.6	32.5	35.4	33.4	32.6
FOSSIL ENERGY	MJ_{eq}	885 000	934 000	908 000	974 000	1 020 000	997 000	977 000

EXPEDITION (1 unit) maximum values		RECONF12	RECONF12 + ACS1	RECONF12 + ACS2	RECONF15, 16	RECONF15, 16 + ACS1	RECONF15, 16 + ACS2	RECONF15, 16 + ACS3
GLOBAL WARMING	kg CO_{2eq}	7 550	7 620	7 650	7 980	8 050	8 090	7 980
OZONE DEPLETION	kg CFC-11_{eq}	$1,14\ 10^{-3}$	$1,15\ 10^{-3}$	$1,20\ 10^{-3}$	$1,21\ 10^{-3}$	$1,22\ 10^{-3}$	$1,22\ 10^{-3}$	$1,21\ 10^{-3}$
PHOTOCHEMICAL OXIDATION	kg $C2H4_{eq}$	3.39	3.42	3.44	3.58	3.62	3.64	3.58
ACIDIFICATION	kg $SO2_{eq}$	43.0	43.5	43.8	45.5	46.0	46.3	45.5
EUTROPHICATION	kg $PO4_{eq}$	9.76	9.86	9.91	10.3	10.4	10.5	10.3
FOSSIL ENERGY	MJ_{eq}	104 000	105 000	105 000	110 000	111 000	111 000	110 000

GATE TO GATE (1 unit) maximum values		RECONF12	RECONF15, 16
GLOBAL WARMING	kg CO_{2eq}	2 330	2 330
OZONE DEPLETION	kg CFC-11_{eq}	$2.15\ 10^{-4}$	$2.15\ 10^{-4}$
PHOTOCHEMICAL OXIDATION	kg $C2H4_{eq}$	1.26	1.26
ACIDIFICATION	kg $SO2_{eq}$	22.7	22.7
EUTROPHICATION	kg $PO4_{eq}$	1.71	1.71
FOSSIL ENERGY	MJ_{eq}	42 800	42 900

Use phase results[2]

USE PHASE (1h of total time[3])		RECONF12, 15, 16	RECONF12, 15, 16 + ACS1	RECONF12, 15, 16 + ACS2
GLOBAL WARMING	kg CO_{2eq}	0.954	0.967	0.959
OZONE DEPLETION	kg CFC-11_{eq}	$8.72\ 10^{-8}$	$8.78\ 10^{-8}$	$8.74\ 10^{-8}$
PHOTOCHEMICAL OXIDATION	kg $C2H4_{eq}$	$4.79\ 10^{-4}$	$4.82\ 10^{-4}$	$4.80\ 10^{-4}$
ACIDIFICATION	kg $SO2_{eq}$	$4.57\ 10^{-3}$	$4.64\ 10^{-3}$	$4.60\ 10^{-3}$
EUTROPHICATION	kg $PO4_{eq}$	$2.89\ 10^{-4}$	$2.93\ 10^{-4}$	$2.91\ 10^{-4}$
FOSSIL ENERGY	MJ_{eq}	18.0	18.3	18.1

Figure 1-28: EPD for Bed-Type milling machine (extract)

Product Category Rules for the machine tools sector within the context of The International EPD® System and related EPDs have been compiled and published recently:

- August 2011: two EPDs for a range of Bed-Type milling machines, build by N.C. Manufacturing S.A. (Nicolás Correa S.A. Group) – Spain, were published under The International EPD® System (see in Figure 1-28). CTME developed the LCA studies in accordance with the standards UNE-EN ISO 14040 and 14044: 2006 series. (http://www.environdec.com/en/Detail/?Epd=8174).
- January 2012: the product category rules CPC Subclass 44214: Machines-tools for drilling, boring or milling metal v1.0 was published. It was prepared by Nicolás Correa S.A. Group and CTME. This PCR is based on CTME's experience in environmental assessment of capital goods and knowledge acquired in LCA studies of 16 milling machines, according to the ISO 14040 series of standards. (http://www.environdec.com/en/Product-Category-Rules/Detail/?Pcr=7945).

The PCR methodology could be transferred to the remaining products, defined as machine tools, taking into account The General Programme Instructions and the PCR Basic Module for CPC Division 44 Special-purpose machinery.

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3 Annex I – VDW classification on Machine Tools

Table 3-1: VDW Machine Tool Classification

INDEX OF MACHINE TOOL TYPES
Metal Cutting Machine Tools
01 Turning Machines (Lathes) and Turning Automatics
02 Drilling and Boring Machines
03 Milling Machines
04 Planing, Shaping, Slotting and Broaching Machines
05 Sawing Machines
06 Grinding Machines
07 Honing, Finishing, Lapping and Polishing Machines
08 Transfer Machines, Machining Centres, Flexible Manufacturing Cells / Production Systems
09 Units for Machine Tools
10 Gear Cutting Machines and Testing Machines
11 Special Purpose Machines built up from Units for Metal Cutting Operations
Physico-Chemical Process Machine Tools
20 Electrical Discharge Machines (EDM)
21 Electro-Chemical Machines (ECM)
22 Thermal Deburring Machines (TEM)
23 Thermal Beam Processing Systems and Beam Sources
24 Other Physico-Chemical Process Machine Tools
Separating Machine Tools (Punching and Shearing Machines)
25 Shears for Sheet Metal Working
26 Shears for Profiled Materials
27 Blanking Presses
28 Combined Punching, Nibbling, Forming and Beam Cutting Machines
29 Other Machine Tools for Separating
Metal Forming Machine Tools
30 Eccentric presses
31 Crank presses
32 Toggle lever presses
33 Fly presses
34 Other mechanical presses
35 Hydraulic presses
36 Bending and straightening presses
37 Presses for Special Applications
38 Press Lines
39 Flexible Automatic Press Lines and Press Systems
40 Hammers
41 Rolling Mills
42 Bending and Straightening Machines

INDEX OF MACHINE TOOL TYPES
43 Drawing Machines
44 Other Metal Forming Machines
45 Special Purpose Machines for Separating and Metal Forming Operations
Control Systems and Software
46 Control Systems for Machine Tools
47 Components for Machine Tool Controls
48 System and Application Software for Manufacturing Processes
Control Systems and Software
50 Planning, Projection, Realization, Starting up, Training

4 Annex II – Classification of product scope

4.1 Metal working machine tools

Table 4-1: Comprised PRODCOM categories for metal working machine tools

PRODCOM	Description
28.41.11.10	Machine-tools for working any material by removal of material, operated by laser or other light or photon beam processes
28.41.11.30	Machine-tools for working any material by removal of material, operated by ultra-sonic processes (excluding machines for the manufacture of semiconductor devices or of electronic integrated circuits)
28.41.11.50	Machine tools for working any material by removal of material, operated by electro-discharge processes
28.41.11.70	Machine-tools for working any material by removal of material, operated by electro-chemical, electron-beam, ionic-beam or plasma arc processes
28.41.11.80	Machine tools for working any material by removal of material, operated by ultra-sonic processes, for the manufacture of semiconductor devices or of electronic integrated circuits
28.41.12.20	Horizontal machining centres for working metal
28.41.12.40	Vertical machining centres for working metal (including combined horizontal and vertical machining centres)
28.41.12.50	Unit construction machines (single station) for working metal
28.41.12.70	Multi-station transfer machines for working metal
28.41.21.23	Numerically controlled horizontal lathes, turning centres, for removing metal
28.41.21.27	Numerically controlled horizontal lathes, automatic lathes, for removing metal (excluding turning centres)
28.41.21.29	Numerically controlled horizontal lathes, for removing metal (excluding turning centres, automatic lathes)
28.41.21.40	Non-numerically controlled horizontal lathes, for removing metal
28.41.21.60	Lathes, including turning centres, for removing metal (excluding horizontal lathes)
28.41.22.13	Numerically controlled drilling machines for working metal (excluding way-type unit head machines)
28.41.22.17	Numerically controlled knee-type milling machines for working metal (excluding boring-milling machines)
28.41.22.23	Numerically controlled tool-milling machines for working metal (excluding boring-milling machines, knee-type machines)
28.41.22.25	Numerically controlled milling machines for working metal (including plano-milling machines) (excluding boring-milling machines, knee-type, tool-milling machines)
28.41.22.35	Non-numerically controlled drilling machines for working metal (excluding way-type unit head machines)
28.41.22.40	Numerically controlled boring and boring-milling machines for working metal (excluding drilling machines)
28.41.22.60	Non-numerically controlled boring and boring-milling machines for working metal (excluding drilling machines)
28.41.22.70	Non-numerically controlled milling machines for working metal (excluding boring-

PRODCOM	Description
	milling machines)
28.41.22.80	Threading or tapping machines for working metal (excluding drilling machines)
28.41.23.05	Numerically controlled flat-surface grinding machines for working metal, in which the positioning in any one axis can be set up to a minimum accuracy of 0.01mm
28.41.23.15	Numerically controlled cylindrical surface grinding machines for working metal, in which the positioning in any one axis can be set up to a minimum accuracy of 0.01mm
28.41.23.25	Other numerically controlled grinding machines in which the positioning in any one axis can be set up to accuracy >0.01mm
28.41.23.35	Non-numerically controlled flat-surface grinding machines for working metal, in which the positioning in any one axis can be set up to a minimum accuracy of 0.01mm
28.41.23.45	Non-numerically controlled cylindrical surface grinding machines for working metal, in which the positioning in any one axis can be set up to a minimum accuracy of 0.01mm
28.41.23.55	Grinding machines for working metal, any one axis can be set to an accuracy ≥0.01mm excluding flat-surface grinding machines, cylindrical surface grinding machines
28.41.23.65	Numerically controlled sharpening (tool or cutter grinding) machines for working metal
28.41.23.75	Non-numerically controlled sharpening (tool or cutter grinding) machines for working metal
28.41.23.85	Honing or lapping machines for working metal
28.41.23.95	Machines for deburring or polishing metal (excluding gear finishing machines)
28.41.24.10	Broaching machines for working metal
28.41.24.30	Gear cutting, gear grinding or gear finishing machines, for working metals, metal carbides or cermets (excluding planing, slotting and broaching machines)
28.41.24.70	Sawing or cutting-off machines for working metal
28.41.24.90	Planing, shaping or slotting machines and other machine-tools working by removing metal or cermets, n.e.c.
28.41.31.20	Numerically controlled bending, folding, straightening or flattening machines for working flat metal products (including presses)
28.41.31.40	Numerically controlled bending, folding, straightening or flattening machines for working metal (including presses) (excluding those for working flat metal products)
28.41.31.60	Non-numerically controlled bending, folding, straightening or flattening machines for working flat metal products (including presses)
28.41.31.80	Non-numerically controlled bending, folding, straightening or flattening machines for working metal (including presses) (excluding those for working flat metal products)
28.41.32.20	Numerically controlled shearing machines for working metal (including presses) (excluding combined punching and shearing machines)
28.41.32.40	Numerically controlled punching or notching machines for working metal (including presses, combined punching and shearing machines)
28.41.32.60	Non-numerically controlled shearing machines for working metal (including presses) (excluding combined punching and shearing machines)
28.41.32.80	Non-numerically controlled punching or notching machines for working metal (in-

PRODCOM	Description
	cluding presses, combined punching and shearing machines)
28.41.33.10	Numerically controlled forging or die-stamping machines and hammers for working metal (including presses)
28.41.33.20	Non-numerically controlled forging or die-stamping machines and hammers for working metal (including presses)
28.41.33.40	Other hydraulic presses, numerically controlled, for working metal
28.41.33.70	Other non-hydraulic presses, numerically controlled, for working metal
28.41.33.80	Other non-numerically controlled presses for working metal[87]
28.41.34.10	Draw-benches for bars, tubes, profiles, wire or the like of metal, sintered metal carbides or cermets
28.41.34.30	Thread rolling machines for working metal, sintered metal carbides or cermets
28.41.34.50	Machines for working wire (excluding draw-benches, thread rolling machines)
28.41.34.70	Riveting machines, swaging machines and spinning lathes for working metal, machines for manufacturing flexible tubes of spiral metal strip and electro-magnetic pulse metal forming machines, and other machine tools for working metal without removing metal

4.2 Wood working machines

Table 4-2: Comprised PRODCOM categories for wood working machines

PRODCOM	Description
28.49.12.10	Multi-purpose machines where the workpiece is manually transferred between operations, for working wood, cork~~, bone, hard rubber, hard plastics or similar hard materials~~
28.49.12.20	Multi-purpose machines where the workpiece is automatically transferred between operations for working wood, cork~~, bone, hard rubber, hard plastics or similar hard materials~~
28.49.12.33	Band saws for working wood, cork~~, bone and hard rubber, hard plastics or similar hard materials~~
28.49.12.35	Circular saws for working wood, cork~~, bone, hard rubber, hard plastics or similar hard materials~~
28.49.12.37	Sawing machines for working wood, cork~~, bone, hard rubber, hard plastics or similar hard materials~~ (excluding band saws, circular saws)
28.49.12.50	Planing, milling or moulding (by cutting) machines for working wood, cork~~, bone, hard rubber, hard plastics or similar hard materials~~
28.49.12.63	Grinding, sanding or polishing machines for working wood, cork~~, bone, hard~~ rubber, hard plastics or similar hard materials
28.49.12.65	Bending or assembling machines for working wood, cork~~, bone, hard rubber, hard plastics or similar hard materials~~
28.49.12.67	Drilling or morticing machines for working wood, cork~~, bone, hard rubber, hard plastics or similar hard materials~~
28.49.12.75	Splitting, slicing or paring machines for working wood, cork~~, bone, hard rubber, hard plastics or similar hard materials~~
28.49.12.79	Machine tools for working wood, cork~~, bone, hard rubber, hard plastics or similar~~

PRODCOM	Description
	~~hard materials, n.e.c.~~

4.3 Welding, soldering, and brazing machines

Table 4-3: Comprised PRODCOM categories for welding, soldering, and brazing machines.

PRODCOM	Description
28.29.70.90	Machinery and apparatus for soldering, brazing, welding or surface tempering (excluding hand-held blow pipes and electric machines and apparatus)
27.90.31.18	Electric brazing or soldering machines and apparatus (excluding soldering irons and guns)
27.90.31.45	Electric machines and apparatus for resistance welding of metal
27.90.31.54	Fully or partly automatic electric machines for arc welding of metals (including plasma arc)
27.90.31.63	Other for manual welding with coated electrodes
27.90.31.72	Other shielded arc welding
27.90.31.81	Machines and apparatus for welding or spraying of metals, n.e.c.
27.90.31.90	Machines and apparatus for resistance welding of plastics
27.90.31.99	Machines and apparatus for welding (excluding for resistance welding of plastics, for arc and plasma arc welding, for treating metals)

4.4 Other machine tools

Table 4-4: Comprised PRODCOM categories for other machine tools.

PRODCOM	Description
28.49.11.30	Sawing machines for working stone, ceramics, concrete, asbestos-cement or like mineral materials or for cold working glass
28.49.11.50	Grinding or polishing machines for working stone, ceramics, concrete, asbestos-cement or like mineral materials or for cold working glass
28.49.11.70	Machine-tools for working stone, ceramics, concrete, asbestos-cement or like mineral materials or for cold working glass (excluding sawing machines, grinding or polishing machines)
28.95.11.33	Combined reel slitting and re-reeling cutting machines for paper and paperboard (excluding film cutting machines and apparatus)
28.95.11.35	Slitting and cross cutting machines for paper or paperboard (excluding film cutting machines and apparatus, combined reel slitting and re-reeling machines)
28.95.11.37	Guillotines for paper or paperboard (excluding film cutting machines and apparatus, combined reel slitting and re-reeling machines, slitting and cross cutting machines)
28.95.11.50	Machines for making bags, sacks or envelopes of paper or paperboard
28.95.11.60	Machines for making cartons, boxes, cases, tubes, drums, or similar containers of paper or paperboard (excluding machines for moulding articles)

PRODCOM	Description
28.96.10.91	Size reduction equipment for working rubber or plastics
28.96.10.95	Cutting, splitting and peeling machines for working rubber or plastics or for the manufacture of products from these materials

5 Annex III – Related machinery (identified modules) (non-exhaustive)

Table 5-1: Comprised PRODCOM categories for related machinery (modular approach)

PRODCOM	Description	Main Drives	Feed Drives	Control Device	Hydraulic Unit	Cooling Lubricant Unit
Categories which are lacking specification, though machineries with modular similarities can be anticipated:						
28961073	Other presses for moulding or forming rubber or plastics, etc, n.e.c.	(x)	(x)	(x)	(x)	(x)
28991190	Other book-binding machines	(x)	(x)	(x)	(x)	
28991390	Other offset printing machinery	(x)	(x)	(x)	(x)	
28991490	Other printing machinery, excluding those of the office type, n.e.c.	(x)	(x)	(x)	(x)	
28993905	Machines for treating metal, having individual functions (excluding robots)	(x)	(x)	(x)	(x)	(x)
28993953	Other machinery for earth, stone, ores, etc, n.e.c.	(x)	(x)	(x)	(x)	(x)
28993955	Other machines and mechanical appliances of HS 84, n.e.c.	(x)	(x)	(x)	(x)	(x)
Categories with closer specification regarding comprised machineries, where modular similarities are highly probable:						
28294200	Calendaring or other rolling machines, excluding metal or glass	x		x	x	x
28491287	Presses for the manufacture of particle board or fibre building board of wood or other ligneous materials, and other machines with individual functions for treating wood or cork	x	x	x	x	x
28941100	Machines for extruding, drawing, texturing or cutting man-made textile materials; machines for preparing textile fibres	x	x	x	x	
28292120	Machinery for cleaning or drying bottles or other containers	x	x	x	x	
28292150	Machinery for filling, closing, sealing, capsuling or labelling bottles, cans, boxes, bags or other containers, machinery for aerating beverages	x	x	x	x	
28292180	Machinery for packing or wrapping (excluding for filling, closing, sealing, capsuling or labelling bottles, cans, boxes, bags or other containers)	x	x	x	x	
28413330	Presses for moulding metallic powders by sintering or for compressing scrap metal into bales	x	x	x	x	x
28491283	Machines and apparatus for electroplating, electrolysis or electrophoresis	x	x	x	x	x
28931400	Presses, crushers and similar machinery used in the manufacture of wines, cider, fruit juices or similar beverages	x	x		x	
28941200	Textile spinning machines; textile doubling, twisting, winding or reeling machines	x	x	x	x	
28941300	Weaving machines	x	x	x	x	
28941430	Circular knitting machines	x	x	x	x	
28941450	Flat knitting machines, stitch-bonding machines and warp knitting machines	x	x	x	x	
28941470	Machines for making gimped yarn, tulle, lace, embroidery, trimmings, braid or net, and machines for tufting	x	x	x	x	
28941530	Printing machinery for printing textile materials (excluding offset,	x	x	x	x	

PRODCOM	Description	Main Drives	Feed Drives	Control Device	Hydraulic Unit	Cooling Lubricant Unit
	flexographic, letterpress and gravure printing machinery)					
28942110	Machinery for the manufacture or finishing of felt or nonwovens in the piece or in shapes (including machinery for making felt hats, blocks for making hats)	x	x	x	x	
28942130	Ironing machines and presses (including fusing presses; excluding calendering machines)	x	x	x	x	
28942150	Washing, bleaching or dyeing machines (including wringers and mangles, shaker-tumblers; excluding household or laundry-type washing machines)	x	x	x	x	
28942170	Machines for reeling, unreeling, folding, cutting or pinking textile fabrics	x	x	x	x	
28942180	Machines used in the manufacture of linoleum or other floor coverings for applying the paste to the base fabric or other support; machines for dressing, finishing, wringing, drying, coating or impregnating textile yarns, fabrics or made up textile articles	x	x	x		
28942230	Household or laundry-type washing machines of a dry linen capacity > 10 kg (including machines that both wash and dry)	x		x		
28951113	Machinery for making pulp of fibrous cellulosic material	x	x	x	x	
28951115	Machinery for making paper or paperboard	x	x	x	x	
28951117	Machinery for finishing paper or paperboard	x	x	x	x	
28951170	Machines for moulding articles in paper pulp, paper or paperboard (including packing for eggs, plates or dishes for confectionery or camping, toys)	x	x	x	x	
28951190	Machinery for making up paper pulp, paper or paperboard, n.e.c.	x	x	x	x	
28961010	Injection-moulding machines for working rubber or plastics or for manufacturing rubber or plastic products	x	x	x	x	x
28961030	Extruders for working rubber or plastics, or for manufacturing rubber or plastic products	x	x	x	x	x
28961040	Blow-moulding machines for working rubber or plastics or for manufacturing rubber or plastic products	x	x	x	x	x
28961050	Vacuum-moulding machines and other thermoforming machines for working rubber or plastics or for manufacturing rubber or plastic products	x	x	x	x	x
28961060	Machinery for moulding or retreading pneumatic tyres...	x	x	x	x	x
28961075	Machinery for moulding or forming rubber or plastics, etc, n.e.c.	x	x	x	x	x
28961082	Machines for processing reactive resins	x	x	x	x	x
28961084	Machines for the manufacture of foam products (excluding machines for processing reactive resins)	x	x	x	x	x
28961097	Machinery for working rubber or plastics or for the manufacture of products from these materials, n.e.c.	x	x	x	x	x
28991110	Folding machines for books	x	x	x	x	
28991130	Collating machines and gathering machines for books	x	x	x	x	
28991150	Sewing, wire stitching and stapling machines for books including for manufacturing of cardboard boxes or like excluding stapling machines for office use, for cardboard box manufacture	x	x	x	x	
28991170	Unsewn (perfect) binding machines for books	x	x	x	x	
28991200	Machinery, apparatus and equipment, for type-setting, for preparing	x	x	x	x	

PRODCOM	Description	Main Drives	Feed Drives	Control Device	Hydraulic Unit	Cooling Lubricant Unit
	or making printing blocks, plates					
28991330	Reel fed offset printing machinery	x	x	x	x	
28991410	Reel fed letterpress printing machinery (excluding flexographic printing)	x	x	x	x	
28991430	Flexographic printing machinery	x	x	x	x	
28991450	Gravure printing machinery	x	x	x	x	
28992020	Machines and apparatus used solely or principally for the manufacture of semiconductor boules or wafers	x	x	x	x	
28992040	Machines and apparatus for the manufacture of semiconductor devices or of electronic integrated circuits (excluding machine tools for working any material by removal of material operated by ultrasonic processes)	x	x	x	x	
28992060	Machines and apparatus used solely or principally for the manufacture of flat panel displays	x	x	x	x	
28993915	Machines and mechanical appliances, having individual functions, for mixing, kneading, crushing, grinding, screening, sifting, homogenizing, emulsifying or stirring (excluding robots)	x	x	x	x	
28993920	Machines for assembling electric or electronic lamps, tubes, valves or flashbulbs, in glass envelopes	x	x	x	x	
28993930	Machines for manufacturing or hot working glass or glassware	x	x	x	x	
28993945	Machines and apparatus used solely or principally for a) the manufacture or repair of masks and reticles, b) assembling semiconductor devices or electronic integrated circuits, and c) lifting, handling, loading or unloading of boules, wafers, semiconductor devices, electronic integrated circuits and flat panel displays	x	x	x	x	
28993950	Rope or cable-making machines	x	x			
28993970	Machines for balancing mechanical parts	x	x		x	

6 Annex IV – Environmental screening of product scope

6.1 Metal working machine tools

Sold volumes and unit values are based on PRODCOM 2009 data, plausibility checked by Fraunhofer and data revised where appropriate. For details see Task 2.

Table 6-1: Environmental screening of metal working machine tools

PRODCOM Code	Label	Sold Volume [units]	Unit Value [€]	
Level of automation: 5 (system) Entirely automated manufacturing plant (may consisting of several machines); automated workpiece (different and similar ones) and tool flow systems as well as supply and waste disposal logistics. Highest potential for impact, due to the multitude of employed components.				
28411270	Multi-station transfer machines for working metal	1.550	498.033	
Level of automation: 4 (cell) NC-machines with automated tool change and automated change of similar workpieces. High potential for impact anticipated.				
28412160	Lathes, including turning centres, for removing metal (excluding horizontal lathes)	2.026	377.793	
28412225	Numerically controlled milling machines for working metal (including plano-milling machines) (excluding boring-milling machines, knee-type, tool-milling machines)	1.321	392.468	
28412315	Numerically controlled cylindrical surface grinding machines for working metal, in which the positioning in any one axis can be set	1.158	513.845	

	up to a minimum accuracy of 0.01mm			
28412430	Gear cutting, gear grinding or gear finishing machines, for working metals, metal carbides or cermets (excluding planing, slotting and broaching machines)	1.057	613.173	
28412240	Numerically controlled boring and boring-milling machines for working metal (excluding drilling machines)	778	628.068	
28412123	Numerically controlled horizontal lathes, turning centres, for removing metal	511	350.000	
28412325	Other numerically controlled grinding machines in which the positioning in any one axis can be set up to accuracy >0.01mm	314	376.829	
Level of automation: 3 (centre) NC-machines with automated tool change. High potential for impact anticipated.				
28411240	Vertical machining centres for working metal (including combined horizontal and vertical machining centres)	3.943	222.158	
28412127	Numerically controlled horizontal lathes, automatic lathes, for removing metal (excluding turning centres)	2.525	171.242	
28411220	Horizontal machining centres for working metal	2.034	480.286	
28412129	Numerically controlled horizontal lathes, for removing metal (excluding turning centres, automatic lathes)	1.879	219.820	
28412305	Numerically controlled flat-surface grinding machines for working metal, in which the positioning in any one axis can be set up to a minimum accuracy of 0.01mm	1.061	121.119	
28412217	Numerically controlled knee-type milling machines for working metal (excluding boring-milling machines)	385	220.729	
Level of automation: 2 (NC-machine) Numerically controlled machines for the automated proceeding of cutting, feed, and advancing motions. Moderate potential for impact anticipated.				
28413360	Non-hydraulic presses for working metal	24.131	16.311	Given the low unit value classification as NC-machine is uncertain
28413120	Numerically controlled bending, folding, straightening or flattening machines for working flat metal products (including presses)	6.146	120.538	

28411110	Machine-tools for working any material by removal of material, operated by laser or other light or photon beam processes	5.963	79.017	
28413140	Numerically controlled bending, folding, straightening or flattening machines for working metal (including presses) (excluding those for working flat metal products)	5.579	47.553	
28413350	Hydraulic presses for working metal	2.506	207.611	
28412365	Numerically controlled sharpening (tool or cutter grinding) machines for working metal	2.699	39.239	
28412223	Numerically controlled tool-milling machines for working metal (excluding boring-milling machines, knee-type machines)	2.538	187.451	
28413240	Numerically controlled punching or notching machines for working metal (including presses, combined punching and shearing machines)	2.097	192.397	
28413220	Numerically controlled shearing machines for working metal (including presses) (excluding combined punching and shearing machines)	1.979	93.489	
28412213	Numerically controlled drilling machines for working metal (excluding way-type unit head machines)	560	185.448	
28411150	Machine tools for working any material by removal of material, operated by electro-discharge processes	517	165.147	
28413310	Numerically controlled forging or die-stamping machines and hammers for working metal (including presses)	342	771.602	
Level of automation: 1 (machine) Machines with cutting and feed drives going without automation. Low potential for impact anticipated.				
28413470	Riveting machines, swaging machines and spinning lathes for working metal, machines for manufacturing flexible tubes of spiral metal strip and electro-magnetic pulse metal forming machines, and other machine tools for working metal without removing metal	57.865	10.464	
28413380	Other non-numerically controlled presses for working metal	40.000	14.166	No revised data available (in task two, no distinction between NC, non-NC)
28412385	Honing or lapping machines for working metal	12.821	14.786	Labelled by CECIMO as NC-machines, but low unit value indicates a significant share of non-NC machines

28413260	Non-numerically controlled shearing machines for working metal (including presses) (excluding combined punching and shearing machines)	10.457	22.406	
28412235	Non-numerically controlled drilling machines for working metal (excluding way-type unit head machines)	9.720	4.606	
28413450	Machines for working wire (excluding draw-benches, thread rolling machines)	6.734	49.114	
28412470	Sawing or cutting-off machines for working metal	6.043	33.454	
28412140	Non-numerically controlled horizontal lathes, for removing metal	5.990	23.927	
28413160	Non-numerically controlled bending, folding, straightening or flattening machines for working flat metal products (including presses)	5.676	35.860	
28412375	Non-numerically controlled sharpening (tool or cutter grinding) machines for working metal	5.243	4.938	
28413180	Non-numerically controlled bending, folding, straightening or flattening machines for working metal (including presses) (excluding those for working flat metal products)	4.827	16.168	
28412270	Non-numerically controlled milling machines for working metal (excluding boring-milling machines)	4.716	11.245	
28412395	Machines for deburring or polishing metal (excluding gear finishing machines)	4.165	44.374	
28411170	Machine-tools for working any material by removal of material, operated by electro-chemical, electron-beam, ionic-beam or plasma arc processes	2.946	38.485	
28412355	Grinding machines for working metal; any one axis can be set to an accuracy >=0.01mm excluding flat-surface grinding machines, cylindrical surface grinding machines	2.384	25.842	
28411250	Unit construction machines (single station) for working metal	1.647	45.679	
28413410	Draw-benches for bars, tubes, profiles, wire or the like of metal, sintered metal carbides or cermets	759	200.464	Not declared as a NC-machine by CECIMO; high single value due to spaciousness, complex and costly

				manufacture of the machine itself, etc.
28411130	Machine-tools for working any material by removal of material, operated by ultrasonic processes (excluding machines for the manufacture of semiconductor devices or of electronic integrated circuits)	637	48.673	
28412490	Planing, shaping or slotting machines and other machine-tools working by removing metal or cermets, n.e.c.	631	55.531	
28412345	Non-numerically controlled cylindrical surface grinding machines for working metal, in which the positioning in any one axis can be set up to a minimum accuracy of 0.01mm	600	58.068	
28412260	Non-numerically controlled boring and boring-milling machines for working metal (excluding drilling machines)	338	109.705	
28412335	Non-numerically controlled flat-surface grinding machines for working metal, in which the positioning in any one axis can be set up to a minimum accuracy of 0.01mm	311	51.808	
28411180	Machine tools for working any material by removal of material, operated by ultrasonic processes, for the manufacture of semiconductor devices or of electronic integrated circuits	297	100.000	
28413320	Non-numerically controlled forging or die-stamping machines and hammers for working metal (including presses)	290	419.604	No tool change (permanently installed ram hammer or the like); no workpiece change (usually workpieces of diverse geometric shape processed); high single value due to spaciousness, complex and costly manufacture of the machine itself, etc.
28413430	Thread rolling machines for working metal, sintered metal carbides or cermets	228	82.895	
28412410	Broaching machines for working metal	67	438.270	Not declared as a NC-machine by CECIMO, given a much higher reported number of units, which has to be ignored after plausibility check
Out of scope Categories which are out of scope (for reasons, see comments in the right column)				

28412280	Threading or tapping machines for working metal (excluding drilling machines)	16.349	833	Unit value < 1.000 Euro
28413280	Non-numerically controlled punching or notching machines for working metal (including presses, combined punching and shearing machines)	11.618	3.377	GER, ES, I: 90% market share, unit values 2.800 - 4.200 Euro; non-industrial use

6.2 Wood working machines[159]

Sold volumes and unit values are based on PRODCOM 2009 data, plausibility checked by Fraunhofer and data revised where appropriate. For details see Task 2.

Table 6-2: Environmental screening of woodworking machines

PRODCOM Code	Label	Sold Volume [units]	Unit Value [€]	Comments
Level of automation: 5 (system)				
---	---			
Level of automation: 4 (cell) NC-machines with automated tool change and automated change of similar workpieces. High potential for impact anticipated.				
28491220	Multi-purpose machines where the workpiece is automatically transferred between operations for working wood, cork, ~~bone, hard rubber, hard plastics or similar hard materials~~	9.858	49.196	

159 Note: Even though indicated by the categories' description, plastic and rubber as well as food processing machines are not involved.

Level of automation: 3 (centre)				
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Level of automation: 2 (NC-machine) Numerically controlled machines for the automated proceeding of cutting, feed, and advancing motions. Moderate potential for impact anticipated.				
28491275	Splitting, slicing or paring machines for working wood, cork, ~~bone, hard rubber, hard plastics or similar hard materials~~	16.448	13.313	
28491267	Drilling or morticing machines for working wood, cork, ~~bone, hard rubber, hard plastics or similar hard materials~~	10.548	11.946	
Level of automation: 1 (machine) Machines with cutting and feed drives going without automation. Low potential for impact anticipated.				
28491210	Multi-purpose machines where the workpiece is manually transferred between operations, for working wood, cork~~, bone, hard rubber, hard plastics or similar hard materials~~	5.270	17.228	
28491250	Planing, milling or moulding (by cutting) machines for working wood, cork, ~~bone, hard rubber, hard plastics or similar hard materials~~	3.568	47.097	
28491265	Bending or assembling machines for working wood, cork~~, bone, hard rubber, hard plastics or similar hard materials~~	2.194	23.428	
28491235	Circular saws for working wood, cork~~, bone, hard rubber, hard plastics or similar hard materials~~	852	63.847	
Level of automation: 0 Categories for which the level of automation are not determinable (for reasons, see comments in the right column)				
28491279	Machine tools for working wood, cork, ~~bone, hard rubber, hard plastics or similar hard materials, n.e.c.~~	31.330	9.219	
28491233	Band saws for working wood, cork~~, bone and hard rubber, hard plastics or similar hard materials~~	7.858	7.957	
28491263	Grinding, sanding or polishing machines for working wood, cork~~, bone, hard rubber, hard plastics or similar hard materials~~	6.375	15.320	
28491237	Sawing machines for working wood, cork~~, bone, hard rubber, hard plastics or similar hard materials~~ (excluding band saws, circular saws)	Approx. 5.000	Approx. 20.000	

6.3 Welding, soldering, and brazing machines

Sold volumes and unit values are based on PRODCOM 2009 data, plausibility checked by Fraunhofer and data revised where appropriate. For details see Task 2.

Table 6-3: Environmental screening of welding, soldering, and brazing machines

PRODCOM Code	Label	Sold Volume [units]	Unit Value [€]	Comments
Level of automation: 5 (system)				
---	---			
Level of automation: 4 (cell)				
---	---			
Level of automation: 3 (centre)				
---	---			
Level of automation: 2 (NC-machine)				
27903181	Machines and apparatus for welding or spraying of metals, n.e.c.	17.367	9.429	
27903199	Machines and apparatus for welding (excluding for resistance welding of plastics, for arc and plasma arc welding, for treating metals)	8.911	24.964	
28297090	Machinery and apparatus for soldering, brazing, welding or surface tempering (excluding hand-held blow pipes and electric machines and apparatus)	4.727	28.940	
27903118	Electric brazing or soldering machines and apparatus (excluding soldering irons and guns)	2.713	26.348	
Level of automation: 1 (machine)				
27903154	Fully or partly automatic electric machines for arc welding of metals	277.321	1.188	"automatic" is understood by the reporting com-

	(including plasma arc)			panies typically as automatic feed of welding wire, but welding tool is manually operated
Level of automation: 0 Categories for which the level of automation are not determinable (for reasons, see comments in the right column)				
27903190	Machines and apparatus for resistance welding of plastics	47.323	2.611	High level of uncertainty regarding type of machines covered, no typical welding machines, presumably packaging and laminating machines and the like
27903163	Other for manual welding with coated electrodes	603.299	216	is likely to include also welding equipment for non-professional use
27903145	Electric machines and apparatus for resistance welding of metal	43.656	12.795	
27903172	Other shielded arc welding	326.963	596	

6.4 Other machine tools

Sold volumes and unit values are based on PRODCOM 2008 data unless stated in comments.

Table 6-4: Environmental screening of other machine tools

PRODCOM Code	Label	Sold Volume [units]	Unit Value [€]	Comments
Level of automation: 5 (system)				
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Level of automation: 4 (cell) NC-machines with automated tool change and automated change of similar workpieces.				

High potential for impact anticipated.				
28951150	Machines for making bags, sacks or envelopes of paper or paperboard	523	366.776	
Level of automation: 3 (centre) NC-machines with automated tool change. High potential for impact anticipated.				
28951135	Slitting and cross cutting machines for paper or paperboard (excluding film cutting machines and apparatus, combined reel slitting and re-reeling machines)	680	235.311	
Level of automation: 2 (NC-machine) Numerically controlled machines for the automated proceeding of cutting, feed, and advancing motions. Moderate potential for impact anticipated.				
28951160	Machines for making cartons, boxes, cases, tubes, drums, or similar containers of paper or paperboard (excluding machines for moulding articles)	14.866	20.180	
28491150	Grinding or polishing machines for working stone, ceramics, concrete, asbestos-cement or like mineral materials or for cold working glass	8.742	26.776	Revised 2009 data, plausibility checked by Fraunhofer
28961091	Size reduction equipment for working rubber or plastics	6.792	19.829	
28951133	Combined reel slitting and re-reeling cutting machines for paper and paperboard (excluding film cutting machines and apparatus)	5.768	51.403	
28961095	Cutting, splitting and peeling machines for working rubber or plastics or for the manufacture of products from these materials	5.622	32.422	
Level of automation: 1 (machine) Machines with cutting and feed drives going without automation. Low potential for impact anticipated.				
28491170	Machine-tools for working stone, ceramics, concrete, asbestos-cement or like mineral materials or for cold working glass (excluding sawing machines, grinding or polishing machines)	20.054	30.549	Non-professional equipment excluded, revised 2009 data, plausibility checked by Fraunhofer
28491130	Sawing machines for working stone, ceramics, concrete, asbestos-cement or like mineral materials or for cold working glass	30.344	6.721	Non-professional equipment excluded, Revised 2009 data, plausibility checked by Fraunhofer
28951137	Guillotines for paper or paperboard (excluding film cutting machines and apparatus, combined reel slitting and re-reeling machines, slitting and cross cutting machines)	47.700	2.088	Only if stationary machines are concerned; low automation anticipated.

28951140	Other cutting machines for paper or paperboard	Approx. 2.000		Only energy-using units considered (former PRODCOM 29551143), based on comments provided by VDMA
Level of automation: 0				
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