Project no.
513673 (SSPI)

Project acronym
EPIC-ICT

Project title
Development of Environmental Performance Indicators for ICT Products on the example of Personal Computers

Instrument STREP

Thematic Priority 8.1.B.1.5, task 6

Deliverable 5
Technical report on methodology

Due date of deliverable: 31 March 2006
Actual submission date: 24 May 2006

Start date of project: November 1st 2004 Duration: 18 months

Lead contractor for this deliverable: IKP

Project co-funded by the European Commission within the Sixth Framework Programme (2002-2006)		
Dissemination Level		
PU	Public	x
PP	Restricted to other programme participants (including the Commission Services)	
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Deliverable 5:

Indication phase

Technical report on methodology

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1 Overview

Deliverable 5 presents the methodology developed in EPIC-ICT and shows typical results at the example of a personal computer (PC).

The EPIC-ICT method consists of four steps to conduct. Simplified, these four steps can be described as

1) Defining the product under consideration properly
2) Building up a model and analyzing the environmental impacts of the product
3) Appraise the main environmental drivers in an understandable way
4) Consider which of these environmental drivers can be influenced practically

The results are called the “Environmental Performance Indicators”. They consist of two sets of indicators, the “Ecological Profile Indicators” and the “Eco-Design Indicators”. The reason to generate two different indicators is the insight that two kind of results are desirable:

- Indicators that reflect the environmental profile of the product (“Ecological Profile Indicators”) and
- Indicators that additionally consider if such an indicator can practically be changed or not (“Eco-Design Indicator”)

This overall procedure is presented in Figure 1. The starting point of the method is a proper description of the product under consideration, followed by the product system modelling in a LCA software with the environmental evaluation (LCIA) as result (step number 2). Depending on the structure of existing data, not always a full LCA study must be conducted. If a suitable modular approach with the respective data behind it available, similar results can be obtained. Also an update of an existing LCA will be possible with significantly reduced effort compared to a “new” full LCA.

In step number 3, the main environmental drivers of the product are presented as “Ecological Profile Indicators”. This results in an overview about what are – from an environmental viewpoint – the most relevant sub-components of a the products and by what the environmental impacts are mainly caused. As step 3 identifies the main environmental drivers, but does not consider if these offer a practical potential for an improvement (as not everything can be changed without limiting the use of a product) in step 4 the practical change potential is included and considered in the result. This leads to the “Eco-Design Indicators”.

As an overall result, a few easy to understand physical product properties remain as indicator which offer the biggest environmental improvement potential that are changeable in practice.

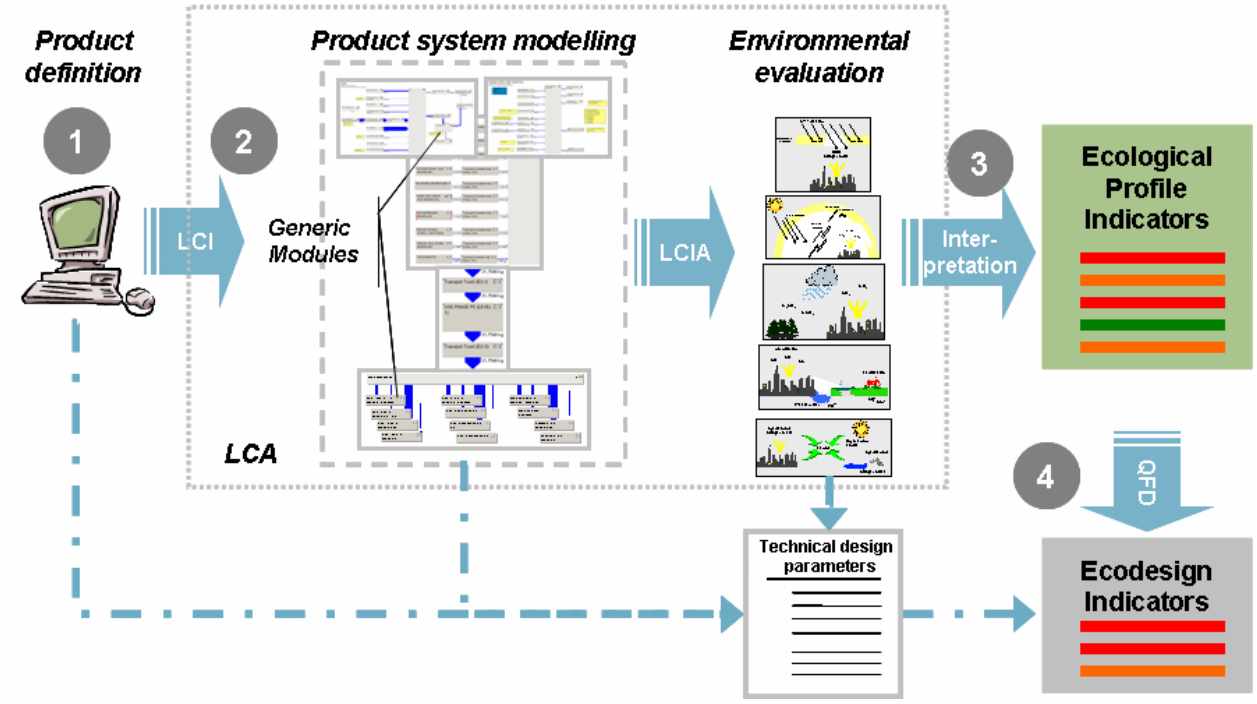


Figure 1: EPIC-ICT Method overview

In the following, the four steps are described shortly. In chapter 2 to chapter 4, the four steps are explained in detail including the example of a personal computer.

Step 1: Product definition phase

- Clearly defines the product under consideration by taking the customer demands and respective required functions into account
- Defines the product from the product designer's perspective and in the designer's "language"
- Results in product definition: Main assemblies of product to fulfil required functions / customer demands

Step 2: Life Cycle Assessment study

- Only one comprehensive full LCA study per product (group) is carried out, which needs to be updated regularly, e.g. every 3 years, depending on product (group) and product development cycles, has to include sensitivity analyses (ensures representativity of study = validity of indicators)

- Main assemblies are broken down into sub-assemblies and components
- Sub-assemblies are modelled with “Generic Modules”: Parameterized, flexible, reliable and consistent partial LCA models, which already include design options
- Enables flexible and adaptable environmental evaluation based on Life Cycle Impact Assessment categories (e.g. Global Warming Potential) and certain Life Cycle Inventory results (e.g. flows of heavy metals)
- Results in “Ecological product profile”: Detailed full scale LCA result, which is needed for an adequate definition of environmental performance indicators of complex products

Step 3: Environmental interpretation

- Identifies stepwise environmentally relevant sub-assemblies and components of the product using contribution analyses
- Results in “Ecological profile indicators”: Reliable, measurable and scientific sound physical product specific environmental performance indicators

Step 4: Eco-design parameters indication

- Combines information from product design (technical specifications and improvement design parameters) and environmental evaluation results from step 3 with adapted QFD approach
- Results in “Eco-design indicators”: Directly usable performance indicators for eco-design of products

2 Step 1: Product definition

- Clearly defines the product under consideration by taking the customer demands and respective required functions into account
- Defines the product from the product designer's perspective and in the designer's "language"
- Results in product definition: Main assemblies of product to fulfil required functions / customer demands

Starting point for the definition of Environmental Performance Indicators is a **clear definition of the product or product group under consideration**. This ensures, that the indicators to be calculated indisputable relate to a determined product or product group, fulfilling specific functions and taking the customer demands into account. This relationship between the environmental improvement potential, when using the indicators for eco-design purposes and the product definition is guaranteed by thoughtfully carrying out the first step of the method.

In short, the first step defines the product from the designer's perspective. The customer demands can generally be expressed in the importance of specific functions of a product for the customer. In the first place, these clearly relate to the selection of main assemblies, which are to be selected to fulfil the technical functions.

On the example of a PC, the **customer demands** comprise the following:

- Internet Access
- E-Mail
- Office tasks / productivity applications
- Multimedia
- Gaming
- VoIP

Depending on the importance of these demands for the customer, different technical functions are of varying importance. This mainly drives the selection of the product's main assemblies.

On the example of a PC, the **technical functions** equal the product's main assemblies and comprise the following:

- Motherboard with CPU

- Random access memory (RAM)
- Hard Disk Drive
- Graphics card
- Sound card
- Cables and ports
- Drives: CD, DVD or Floppy
- Chassis
- Power Supply Unit
- Monitor
- Mouse / Keyboard
- Cooling system

Taking the relationship between the demands and technical functions into account ensures the reliability of the method's overall results: The Environmental Performance Indicators. It prevents from receiving improvement potentials, which are not in line with the functions the product needs to fulfil from the customer's perspective.

In the EPIC-ICT project, the Dell OptiPlex desktop PC GX280 with a 17" CRT monitor has been chosen exemplarily. This PC represents the best selling Dell desktop PC in Europe (2004). This information is based on actual sales in the European market of what has been ordered by purchasers.

Typical user: The GX280 is a scalable desktop capable of meeting the needs of a broad range of users in corporate and institutional environments. With a typical minimum 15-month life cycle, the GX280 is for customers who rely on stable platforms with relevant technology to help minimize the overall cost of ownership.

For the European institutional-type (Government) purchaser, the most popular OptiPlex configuration is:

- Marketing Model: GX280 SMT (Small Mini-tower)
- Processor: P4 2.8GHz
- Memory: 256MB
- Hard Drive: 40GB
- RMSD: CD-ROM

- Monitor: 15” CRT monitor
- Data Entry devices: entry level mouse & keyboard
- Operating System: Windows XP

This definition of the baseline case study, which is carried out in the EPIC-ICT project, represents the starting point of the following steps. For this product, Environmental Performance Indicators are defined.

Figure 2: Product chosen for baseline PC study: Dell GX280 desktop computer

3 Step 2: LCA model and Environmental Evaluation

As shown in Figure 1, the second step of the method consists in carrying out a detailed Life Cycle Assessment of the defined product, from which Ecological Profile Indicators will be derived. At this stage, it is very important that the depth and accuracy of the LCA fully reflect the complexity of the product. The product's environmental performance is then adequately assessed by means of Environmental Performance Indicators, expressed with measurable physical units.

The activities performed in step 2 of the EPIC-ICT method are illustrated in Figure 3. They will be analysed and commented in the following paragraphs.

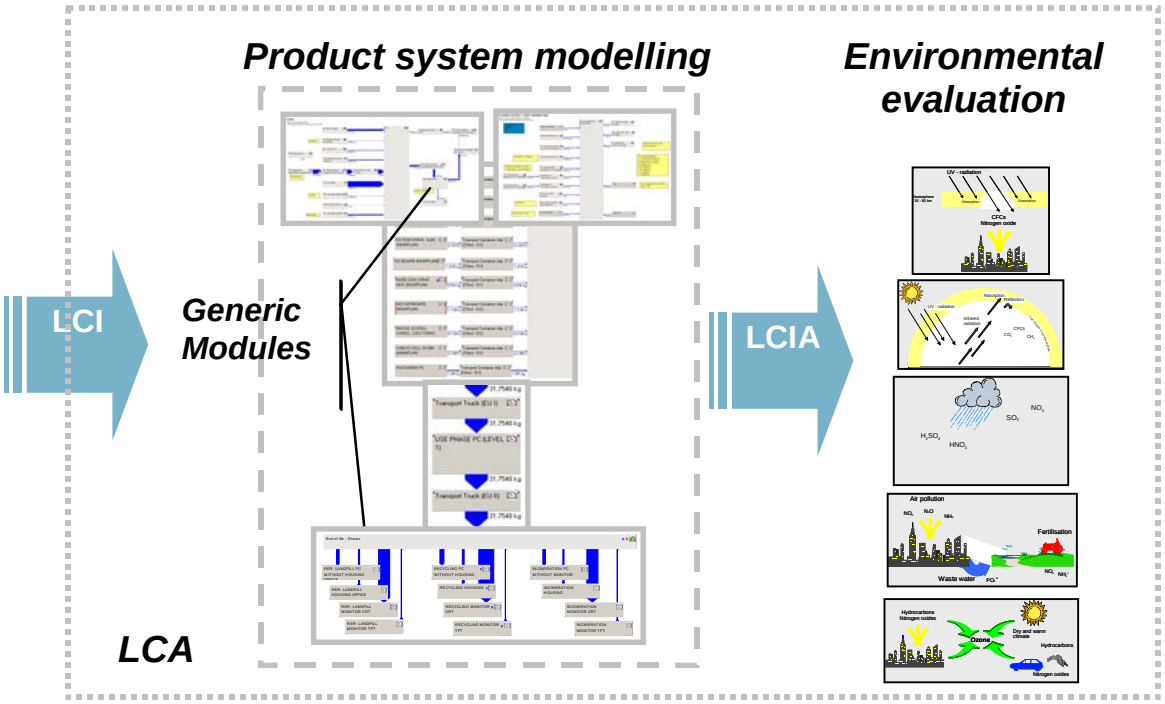


Figure 3: Elements of the LCA study carried out in step 2 of the EPIC-ICT method

3.1 Product system modelling

The product's complexity is reflected in the **product system model**. The Life Cycle Model of the product and its inventory of environmental relevant flows, is the backbone of the subsequent **environmental evaluation** by means of Life Cycle Impact Assessment (LCIA).

In order to reflect the whole life cycle of the product, the system model needs to take all phases into account: production, use, transports and end of life. The production includes all processing and transportation steps from raw material extraction to the final product to be delivered to the customer. The use phase takes into account all processes during the lifespan of the product. On the example of a PC, the electricity

consumption dominates this phase. The end of life needs to be taken into account as well, as in principle it represents a relevant part of the life cycle. Transportations for delivering the product to the customer and for end of life are also included.

In order to ensure accuracy and verifiability, priority was given to the collection of primary data, either provided by producers or measured. Whenever this was not possible, updated datasets have been used, as well as specific literature sources.

The table below summarizes the main data sources for the PC model, split per life cycle phases.

Table 1: Main data sources for the Life Cycle Inventory

Life cycle phase	Main sources
Manufacturing	Philips LCA database, primary data from Dell, empirical measures from Motorola, primary data from other external producers, literature studies
Use phase	Direct data from Dell + EPA
End of life	Information from industry, literature sources, Internet search

As for upstream information (e.g. materials and energy systems), in general aggregated datasets from LCA databases were taken, since these represent and include all relevant information. The background datasets are consistently taken from the GaBi 4 database (see www.gabi-software.com)

The information collected in the way indicated was modelled into GaBi 4 through Generic Modules, which are described more into detail in the following sub-paragraph.

As far as the manufacturing of the PC is concerned, the model consists of partial LCA models of the following main assemblies (according to step 1):

- Housing of the PC: Housing of the PC with several plastic and metal parts, some smaller electric parts like switches, LEDs etc.
- Power supply unit: Mainly the populated PWB, coil and capacitors as well as fans, other electronic components and some steel sheets used in this part.

- Motherboard: Populated FR4 motherboard including ICs, capacitors, resistors, plugs etc. The processor and the processor cooling are own very detailed models in this sub-module.
- CD Rom drive: Parts of the CD-ROM/DVD with some steel and plastic parts, electromechanical parts (e.g. motor), populated PWB etc.
- HDD: Various plastic, metal, electromechanical parts (e.g. motor), data disks etc.
- Cables: All cables, mainly copper cables with insulation like the IDE cables, the power cable, the power supply cables for the main board etc., includes the respective plugs
- Monitor: Detailed models of a CRT and a TFT display including mechanical parts (plastics, metals), CRT resp. the LCD panel production, populated PWBs, power supplies etc.
- Keyboard and mouse: Detailed models of mouse and keyboard including all mechanic and electronic parts, populated PWBs etc

3.2 Modelling with Generic Modules

The partial LCA models, listed above for the production but also applied for the other life cycle phases, are broken down into more and more detailed elements, depending on the complexity of the regarded product or life cycle aspect. Within the EPIC-ICT methodology, it is proposed to use the modelling approach of Generic Modules, which enhance the flexibility of Life Cycle Models.

The approach of Generic Modules is applied to manage complex product models and offer the link between Life Cycle Assessment and Design for Environment. It gives the opportunity to provide transparent and summarized results with an acceptable time for the designer. This is realized by forming flexible models with parameter variation that include readily modelled parts and sub-assemblies. These parameters allow the variation of product models. This gives the opportunity to adapt the modules to specific product properties and subassembly modifications or modelling design scenarios without the need of forming entirely new modules. By combining the Generic Modules, different phases of a product life cycle can be efficiently modelled and analyzed. Sub-assemblies and components should preferred be modelled with (existing) Generic Modules. The use of Generic Modules leads to parameterized, flexible, reliable and consistent models, which can be easily adapted and changed e.g. for scenario analysis. Anyway, it is not a necessary precondition for the method.

The strength of parameters is the possibility to make different versions of the model, allowing the immediate creation of several scenarios. In fact, the variations applied in a Generic Module automatically update the entire model. Parameters in Generic Modules reflect and combine environmental relevance and design options: Design expert knowledge (what to parameterize? which units?) and environmental expert knowledge (what is relevant from environmental point of view?).

Different scenarios are useful in making semi-automatic sensitivity analysis.

The variation via parameters is possible on material, manufacturing process, component or sub-assembly level. It allows the adaptation of the Generic Module of e.g. a resistor or a substrate to similar resistors or substrates by parameter variation that reflects main technical changes or differences. This applies for nearly all sub-assemblies. As an example, the parameters for the F4 printed wiring board are: Number of layers, surface area and mass of the PWB. Additionally, the model is open to other changes.

The method is already established and many data sets for electronic assemblies already exist.

Some parameter changes apply to the whole model, and not only to single sub-assemblies. These parameters are:

- PC type (where “0” indicates an office PC, “1” a gamer)
- Drive type (where “0” indicates a CD-Rom, “1” a DVD)
- Monitor type (where “0” indicates a 17’’ CRT and “1” a 15” TFT screen)

As far as the use phase and end of life phases are specifically concerned, parameter variations are established as follows:

- Use phase: two use patterns are defined basing on different hours at different use modes
- End of life: three end of life destinations are defined, namely recycling, incineration and landfill disposal. They are defined separately for the monitor, the computer without housing and the housing

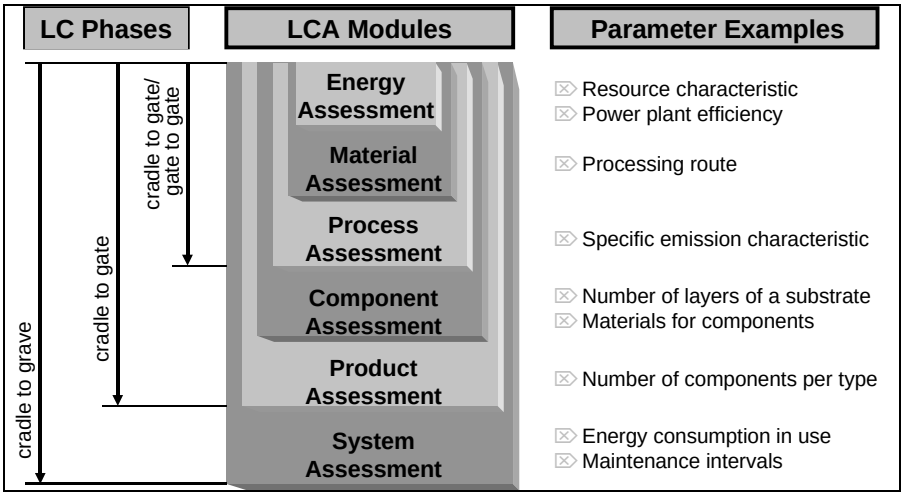
The common agreement on the principle of the approach of Generic Modules is also underlined by looking at parallel approaches, e.g. from industry applied Ecoscan approach (e.g. Philips) or the EIME tool developed and/or applied from French electronic companies such as Alcatel, SGS Thomson or HP. All of these approaches follow the modular thinking in analysing environmental effects of complex products. It is always not a common practice to use aggregated lists of materials and/or components for the entire products, because the analysis is not possible to be carried out from such an aggregated perspective respectively from top down view.

3.2.1 "Manual" for setup of new GMs and refining of available GMs

In principle the procedure for creating LCA processes is as described in the following table. The general approach step by step is explained on left side of the following table and an exemplarily setup is given on the right side on behalf of a semiconductor component (IC).

The table shows the setup of new Generic Modules and can be used as a manual to be applied to other components or complex products. In view of the case study on a personal computer chapter 4.1 of this report provides an overview of the main important modules, which have been applied.

General approach for setup new Generic Modules	**Example for setup the Generic Module 'chip production'**
In the first step the product and the product system boundaries under consideration have to be defined. The following graph shows the modular structure of the general Generic Modules.	The specific system boundaries of a chip production are defined as follows. For simplification it is decided to take the main materials into consideration, i.e. the mono crystalline silicon for the die, the housing material, the gold bond wires, the lead frame material (alloy). For processing the IC the energy consumption is detected as main important process, thus the power consumption per produced area of die (wafer manufacture delivers information on power consumption per square cm wafer production) is taken into consideration. For simplification no difference between front end and back end is made.



GRAPHIC OF THE MODULAR STRUCTURE OF GENERIC MODULES OF ELECTRONIC CHIP PRODUCTION

Energy module	
Energy modules can be seen as the base of all LCA modules, as energy is used in almost all processes. The energy models itself reflect LCA process for providing thermal energy or power via different technologies and due to regional aspects. Resources and their treatment, e.g. burning and making steam for generators, plus resulting	Different energy modules are available, e.g. power plants ready to be used reflecting entire LCA data for provision power (cradle to gate) or even on a higher aggregation level providing national grid mixes with respective LCA data for power from DE, FR or GB or on an even higher aggregated level, providing power modules relating to EU25 mixes.

emissions and wastes have to be taken into consideration. General LCA procedure and considerations have to be applied. Possible parameters could be tuning respective technologies, e.g. efficiency or filters, or quantification of different technologies to reflect composition of grid mixes.	These Generic Modules can be applied to all processes, which have energy demand on input side, e.g. process steps for production of materials or assembly lines or use phases.
Material module	
A crucial base of defining products is given by materials. It is necessary to know all relevant material inputs and the respective environmental profile of the used materials. Therefore make a list of all material inputs into the product and then rank that list on base of their environmental profile. There are different methods possible to do this kind of ranking, e.g. single point indicator, weighting of categories etc. The Generic Modules of energies can be applied in the LCA process models for materials, where applicable. General LCA procedure and considerations have to be applied.	The material inputs for the chip production are epoxy resin, glass fibers, tin, lead, gold and mono crystalline silicon according to system boundary definitions. The materials on waver (contactors, semi-contactors, dielectrics) are neglected due to their low mass and their low environmental profile impact.
Specific cut-off criteria are defined for each product. Cut-off criteria are in principle based on the relevance by mass, energy or environmental effectiveness. General LCA procedure and considerations have to be applied.	Specific cut-off criteria for the usage of materials in the chip production are used, e.g. materials below 5% by mass and 5% by environmental relevance can be neglected. Expert judgements of neglected materials should give evidence of made decisions for exclusions.
Manufacturing module / process module	
Beside the materials a product is also made by processing those materials. The manufacturing module reflects the technical processes considering input materials, energies and auxiliaries on input side and respective products, emissions and wastes on output side. Via parameter the respective materials and energies can be quantified on base of technical dependencies. The manufacturing process should be representative (horizontal or vertical mix). Cut-off criteria can be defined similar to the material and energy modules. General LCA procedure and considerations have to be applied.	In the example of the die production the energy consumption per die size is the most relevant input. The consumption of auxiliaries is neglected, if it is in accordance with the defined system boundaries, e.g. due to lower relevance - application of defined cut off criteria. For the energy consumption respective energy modules can be selected
Component module and product module	
Components are mainly defined by materials, energies and manufacture. Respective already prepared modules can be selected. Technical dependencies should be introduced by parameter as much as possible, in order to allow a feasible tuning of a Generic Module on a relatively high aggregation level.	The IC model reflects a Generic Module of a component or product, providing parameters to tune technical aspects of an IC, e.g. mass of epoxy and glass fibre, length and diameter of gold bond wire, size of die (which calculates the mass of monocristalline silicon) and amount of power demand per size of die.
System module	
All life cycle phases of a product can base on Generic Modules. The definition of goal and scope of the model	The Generic Module of IC could have the discussed parameters for manufacture phase, an additional parameter

defines the parameters relating to complexity or simplification, depth of variable hierarchies and throughout the life cycle phases.	for the use, defining the intrinsic power loss and no further free parameter in End of Life (EoL) as it might be defined by average EoL scenarios.
Setup of the model (material with ranking, manufacturing process, cut-off criteria, technical dependencies, parameter settings (fixed, free))	
The definition of the product in the beginning of the modeling delivers some technical dependencies which have to be considered. These technical dependencies define parameters which are used in the Generic Module. Those parameters could be free parameters or depending parameters. Depending parameters are parameters which are calculated or are fixed values. Free parameters are those which could be changed for each considered product type. The complexity and reflected dependencies for and among the parameters can be set in accordance to intended complexity or simplification. Certainly their definition must also be in regard to general LCA procedure for applied cut off criteria, representativness or reliability.	Modeling the chip production as a Generic Module means that the defined materials and manufacturing process are build up in relation to the intended representativeness. The decision of free, fixed and dependent parameters can be different for the same component, e.g. the gold content may be defined by bond wire length and diameter (free parameters) or is defined automatically in relation to the die size and housing largeness (dependent parameter) or can be fixed in a proportion of the entire mass (fixed parameter).
Usage of the Generic Module	
Only as free defined parameters are accessible in the model. These accessible parameters are in best case given in designer's language (understandable from technology people not only from LCA experts) and are product technology related. This broadens the applicability also for non-experts of LCA.	Comments on the parameters should help the user to understand the tuning, e.g. naming die size instead of energy consumption per size of produced wafer. As a principle, the technology relation is more important than the LCA language. If another chip type (important: only another mono crystalline silicon type could be compared) should be considered, the free parameters have to be adapted on the specifications of this type. If e.g. a gallium/arsenide (GaAs) chip type should be considered a new Generic Module has to be created according to the steps mentioned above.

3.2.2 Environmental evaluation

The Environmental Performance Indicators are based on both, the results of an Impact assessment (LCIA) according to ISO 14040 and on taking several flows of the life cycle inventory into account. The LCIA assesses the life cycle model of the product from an environmental point of view by modelling selected environmental issues, so-called impact categories. Results from an LCIA represent the environmental impacts of the products. The EPIC-ICT method is flexible in the choice of the impact categories, in order to reflect product specific environmental issues and user preferences.

The environmental evaluation in the project included various comparisons with other LCA studies on personal computers and on using different impact assessment

methods. It was found that the study is in line with findings from other studies and that results point in the same direction - with respect to ecodesign - indifferent which impact assessment method was chosen.

3.2.3 Result of LCA study

Result of this step, a detailed full-scale LCA, is the "Ecological product profile" and the life cycle model, built on Generic Modules. The level of detail needs to be in line with the product's complexity. Only then an adequate definition of environmental performance indicators of complex products is feasible.

The results for the PC, that are described in the next chapter (Figure 5), are considered for the environmental impact categories recommended by EPIC-ICT plus several considered emissions on LCI level (Table 2). More details on the selection of impact categories and emissions can be found in Deliverable 3 (public available, e.g. at www.epic-ict.org).

Impact categories and LCI results for interpretation		**Unit**	**Method (where applicable)**
Environmental Impact categories:			
AP		[kg SO_2 Equiv.]	CML 2001
EP		[kg PO_4^{---} Equiv.]	CML 2001
GWP		[kg CO_2 Equiv.]	CML 2001
ODP		[kg R11 Equiv.]	CML 2001
POCP		[kg C_2H_2 Equiv.]	CML 2001
Primary energy		MJ	
LCI indicators:			
Emissions contributing to human health and eco-toxicity:		kg	
Acrylonitrile	Organic emissions to fresh water		
Aluminum	Inorganic emissions to fresh water		
Arsenic	Heavy metals to air		
Cadmium	Heavy metals to air		
Chromium (unspecified)	Heavy metals to air		
Copper	Heavy metals to fresh water		
Copper	Heavy metals to industrial soil		
Hydrogen fluoride	Inorganic emissions to air		
Mercury	Heavy metals to air		
Nickel	Heavy metals to air		
Nickel	Heavy metals to fresh water		
Nitrogen oxides	Inorganic emissions to air		
NMVOC (unspecified)	Organic emissions to air		
Polychlorinated dibenzo-p-dioxins (2,3,7,8 - TCDD)	Organic emissions to air		
Polycyclic aromatic hydrocarbons (unspec.)	Organic emissions to fresh water		
Sulphur dioxide	Inorganic emissions to air		
Vanadium	Heavy metals to air		
Vanadium	Heavy metals to fresh water		
Zinc	Heavy metals to air		
Zinc	Heavy metals to industrial soil		
Water consumption (renewable resources)		l or m3	
Additional indicators			
Electricity consumption during use phase		kWh	

Table 2: Recommended list of impact categories and inventory results for Personal Computers

4 Steps 3 and 4: Environmental Interpretation and Identification of Environmental Performance Indicators

In EPIC-ICT the interpretation of results of the full LCA study focuses on the following:

- Identification of environmental significant issues of a PC
    - On main assembly level
    - On sub-assembly level
    - On specific product characteristic level
- Sensitivity, completeness and consistency checks

Goal of EPIC-ICT is to provide a method that simplifies the consideration of environmental issues in the product design phase. For this reason, Ecological Profile Indicators are to be identified in step 3, which indicate the environmentally most relevant product specifics. In the following Step 4, Eco-design Indicators, which take design parameters (such as change potential and major known dependencies between indicators into account), are provided by the proposed method.

Both types of indicators are Environmental Performance Indicators.

Ecological Profile Indicators (result of step 3) are directly based on the LCA results. By means of using the Generic Modules approach for modelling, the physical quantities of the environmentally relevant life cycle aspects of the product can be identified easily. The Generic Modules combine product designer knowledge (what are the parameters?) with environmental expert knowledge on the product part (what is relevant from environmental point of view?).

Eco-Design Indicators (result of step 4) are based on the list of Ecological Profile Indicators and take into account, that several product aspects over the life cycle can not or only limited be influenced, respectively depend on each other. Therefore the method allows taking the change potential and dependencies of options into account. This reduces the number of indicators those which are then directly applicable for eco-design in industry are filtered out.

4.1 Step3: Environmental interpretation - Deriving Ecological Profile Indicators

Procedure Step 3:
A: Identify most relevant main-assemblies or technical life cycle aspects – Relevance criteria: 80 % of contribution to environmental impacts covered or at least 5 main assemblies
Example: Motherboard [PC Production], Power consumption PC [Use phase]

B: Identify most relevant sub-assemblies or technical life cycle aspects in most relevant main-assemblies – Relevance criteria: 80 % contribution to environmental impacts covered
Examples: PWB assy [Motherboard] [PC Production], Memory assy [Motherboard] [PC Production]

C: Identify most relevant components or technical life cycle aspects of most relevant sub-assemblies / aspects – Relevance criteria: 80 % contribution to environmental impacts covered and within sphere of influence and change potential is given
Example: FR4 [Printed Wiring Board] [Motherboard] [PC Production]

D: Take physical metrics of identified most relevant components / aspects as reference for environmental performance which are in sphere of influence for the designer / producer (parameters of Generic Modules) – "Ecological Profile Indicator"
Examples: m2 FR4 size [Printed Wiring Board] [Motherboard] [PC

The identification of the Ecological Profile Indicators is carried out in a stepwise procedure by following a prioritisation rule. In the latter analyses the life cycle environmental impacts of each PC component from the more general level to the single and smallest sub-components – and related processes – is conducted. This prioritisation is performed via a contribution analysis of the life cycle phases and product components. The most environmentally relevant components and processes are those contributing together to 80% of the overall environmental indicator result (i.e. impact categories, toxic relevant flows and water) of the regarded level (main assembly or sub-assembly level). Regarding the production phase, it was additionally decided to identify at least the five sub-assemblies which contribute the most to the overall results.

The accuracy of the environmental interpretation through the mentioned prioritisation rule is also a good guidance to understand how much effort should be put into the depth of detail of the modelling of the respective Generic Modules.

This 80% contribution rule is not to be seen as a strict rule, but as a guideline which helps to decide where to concentrate on in eco-design effort.

Starting from the overall LCA results and considering the ecological profile over the whole life cycle, the following procedure to identify the Ecological Profile Indicators is applied in the EPIC-ICT method (Figure 4).

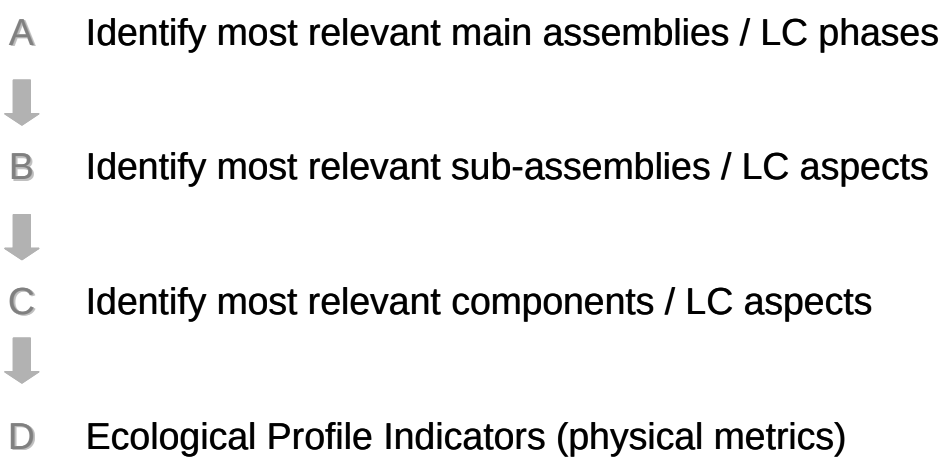


Figure 4: Procedure for deriving Ecological Profile Indicators

In a first step, the most relevant main assemblies or life cycle stages are identified according to the relevance criteria of 80% contribution to environmental impacts (or at least five main assemblies).

After this first environmental screening, a deeper analysis is carried out within each relevant assembly and life cycle phase, in order to identify the most environmentally relevant sub-assemblies and life cycle aspects. This activity further drives to the identification of the most relevant components and processes, down to the deepest level. The ultimate step is to derive Ecological Profile Indicators, expressed in physical units (mass, amount, etc.).

It is worth remembering that those assemblies or life cycle phases, which are responsible for very limited impacts, are not neglected from the EPIC-ICT method. Every component, process and product stage are in fact taken into account for the definition of the Eco-Design Indicators. The 80% contribution rule identifies the priorities for eco-design.

The results from the application of each step of the methodological procedure described are reported below.

A Identify most relevant main assemblies or life cycle phases – Relevance criteria: 80 % of contribution to environmental impacts covered, or at least five main assemblies

The most relevant environmental product parts on main assembly level and per main life cycle phase of a personal computer are identified as follows:

Manufacturing:

- CRT monitor
- Motherboard
- Housing
- Power supply unit
- Hard disk drive

Distribution / Transport

- No relevance

Use phase:

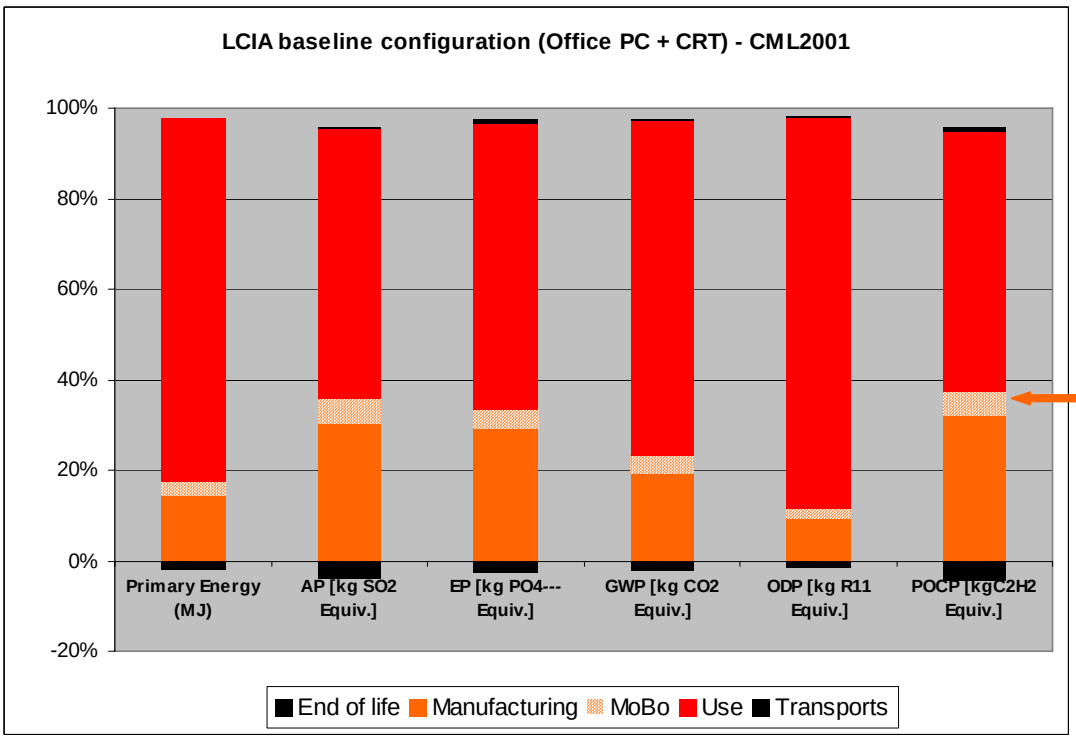
- Electricity consumption PC
- Electricity consumption Monitor

End of Life:

- No relevance

These results are reflected in the following Figure 5, which shows the relative importance of the main life cycle phases to overall environmental impacts. As it is possible to see, the use phase dominates, being responsible for over 50% of total environmental impacts. The second largest contributor is the manufacturing phase (in the 15-50% range). The graph highlights as an example the contribution of the motherboard (see other steps below).

Transports and end of life do not produce significant impacts.



Red: >50% Orange: 15-50% Black: <15%

Figure 5: Step A: Identification of the most relevant assemblies and life cycle stages

These results are the basis for further and deeper going analysis. The following step (step B) is the identification of most environmentally relevant sub-assemblies and technical aspects. Below two examples are reported with regard to the Motherboard and the use phase of the PC.

B Identify most relevant sub-assemblies or technical life cycle aspects in most relevant main assemblies – Relevance criteria: 80 % contribution to environmental impacts covered

From an in-depth analysis of the red and orange bars shown above (Figure 5), the following results are obtained according to the 80% contribution rule:

Manufacturing (only example Motherboard):

- PWB assembly
- Memory assembly
- CPU
- Connectors

Use phase (example Electricity consumption PC):

- Min mode

From the examples provided, it is possible to derive some comments:

- As for the manufacturing phase, the four sub-assemblies listed above are responsible for over 80% of the environmental impacts related to the manufacturing of the Motherboard
- With respect to the use phase, the consumption of the PC in min mode is responsible for over 80% of the environmental impacts, while the max mode, sleep mode and off mode consumption all together contribute to the rest.

These aspects are further analyzed in step 3, which takes into account single components (still expressed as units or phases).

C Identify most relevant components or technical life cycle aspects of most relevant components / aspects – Relevance criteria: 80 % contribution to environmental impacts covered and within sphere of influence and change potential is given

In Step C the most relevant components or technical aspect of step B are identified as follows:

Manufacturing (only example Motherboard – PWB assembly):

- FR4 (6l Au/Ni finishing)
- Processor (North/Southbridge)

Use phase (example Electricity consumption PC – min mode):

- Not applicable at component level

D Take physical metrics of identified most relevant components / aspects as reference for environmental performance which are in sphere of influence for the designer / producer (parameters of Generic Modules) – "Ecological Profile Indicator"

In this last step the components and technical aspects are combined with their physical metrics. There the parameters of the Generic Modules are transferred into designer's language. In the following the components and technical aspects of step C are combined with the physical metrics.

Manufacturing (example Manufacturing – Motherboard – PwB):

- FR4 (6l Au/Ni finishing) m² FR4
- Processor (North/Southbridge) m² die size

Use phase (example Electricity consumption PC – min mode):

- kW power demand
- Hours of use

The following figure gives a short overview of the above mentioned steps A – D. The different colours symbolize the different contributions of the main-assemblies respectively the sub-assemblies.

More than 50% contributions to the overall results are marked red, 15 – 50% are marked orange and 0 – 15% are depicted in black. Together 80% of the overall contribution is covered. This colour legend applies for all steps.

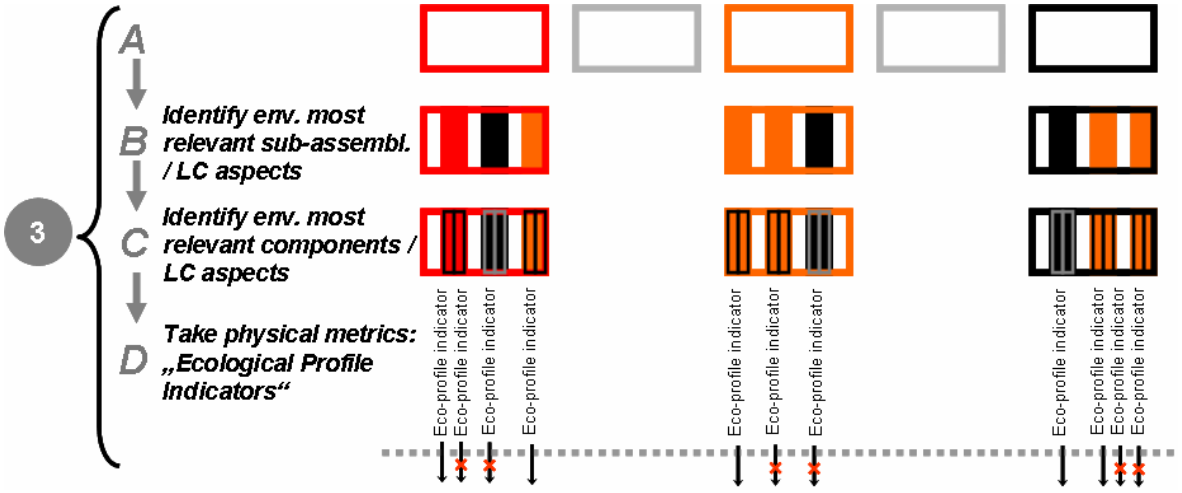


Figure 6: Step 3: Deriving Ecological Profile Indicators

A complete overview of all steps is given in the following table, focusing on the example of the motherboard.

Table 3: Definition of Ecological Profile Indicators for the Motherboard

Motherboard	PWB	FR4 (6l Au/Ni finishing)	m^2 FR4
		Processor	m^2 die size
	Memory	PWB FR4	m^2 FR4
		Memory ICs	m^2 die size
		Gold plating	kg gold
	CPU	n/a	m^2 die size
	Connectors	Gold plating	kg gold
		EMS shielding	kg EMS sheet
		PBT granulate	kg PBT
A	B	C	D
Assembly level	Sub-assembly level	Component level	Physical unit level

Figure 5 shows the whole procedure applied to derive Ecological Profile Indicators with respect to the Motherboard manufacturing.

The same methodological steps are provided in Table 4 and Figure 8 with respect to the electricity consumption in the use phase.

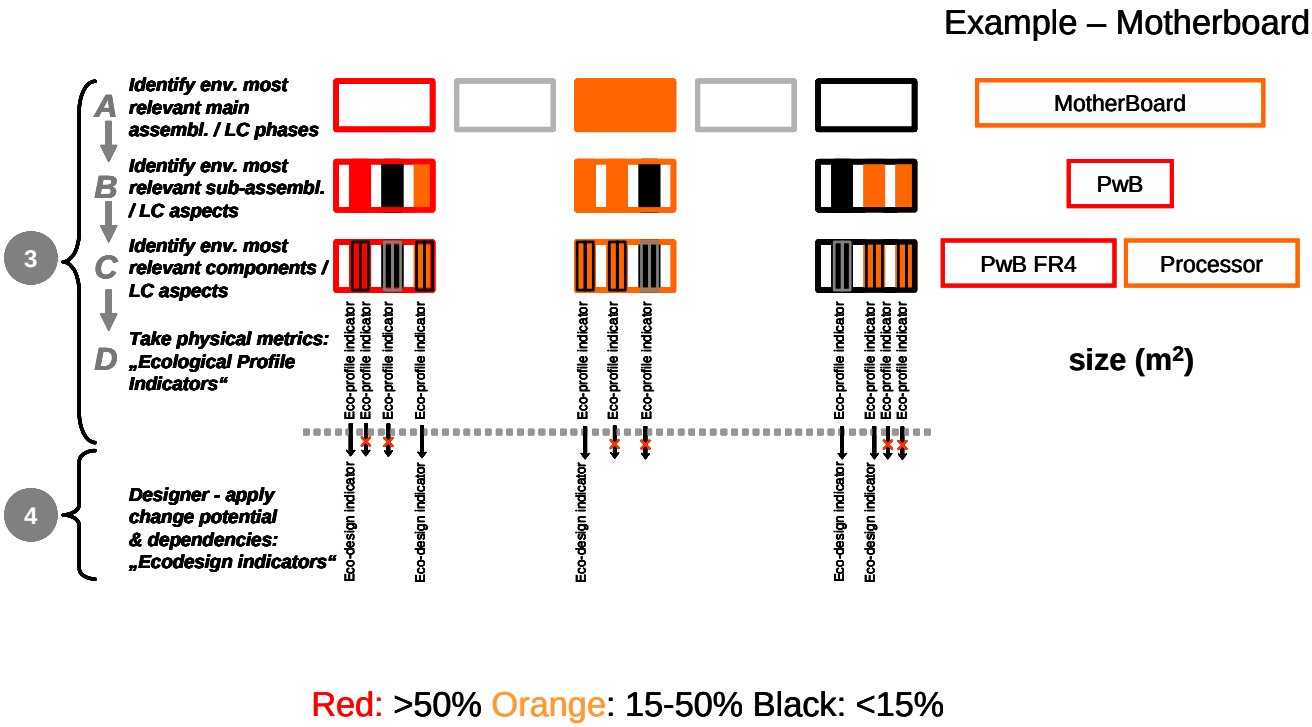


Figure 7: From environmental evaluation to ecological profile indicators – Example of the Motherboard

Table 4: Definition of Ecological Profile Indicators for the electricity consumption in the use phase

Electricity consumption PC	Off mode	n.a.	kW power demand Hours of use
	Sleep mode	n.a.	
	Max mode	n.a.	
	Min mode	n.a.	
Electricity consumption monitor	Off mode	n.a.	kW power demand Hours of use
	Sleep mode	n.a.	
	Max mode	n.a.	
	Min mode	n.a.	
A	B	C	D
Assembly level	Sub-assembly level	Component level	Physical unit level

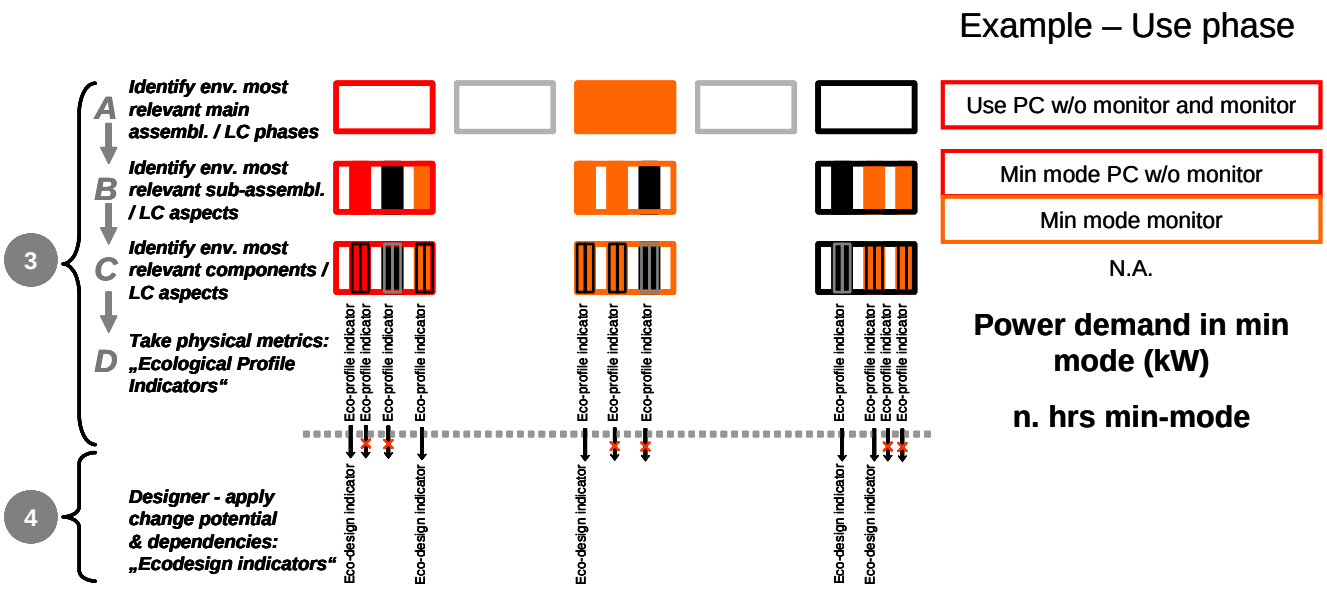


Figure 8: From environmental evaluation to ecological profile indicators – Example of the electricity consumption in the use phase

4.2 *Step4: Eco-Design Indicators*

After having identified the Ecological Profile Indicators in step 3, in this step the Eco-Design Indicators are derived. These indicators base on the list of the Ecological Profile Indicators and take product designers constraints into account. A reduced number of indicators, which can directly be used for Eco-Design, is resulting.

This is done by means of an adapted QFD+-approach in order to take change potentials and dependencies of indicators into account.

- Change Potential: Considers technical and economic feasibility for defined product influenceable by designers
- Dependencies: Considers interrelations between proposed indicators in such a way that the improvement of one indicator may increase or decrease other detected indicators, which is then reflected in the list of Eco-Design indicators

The designer's options in product design, which is directly related to the physical quantities identified in step 3, is generally limited.

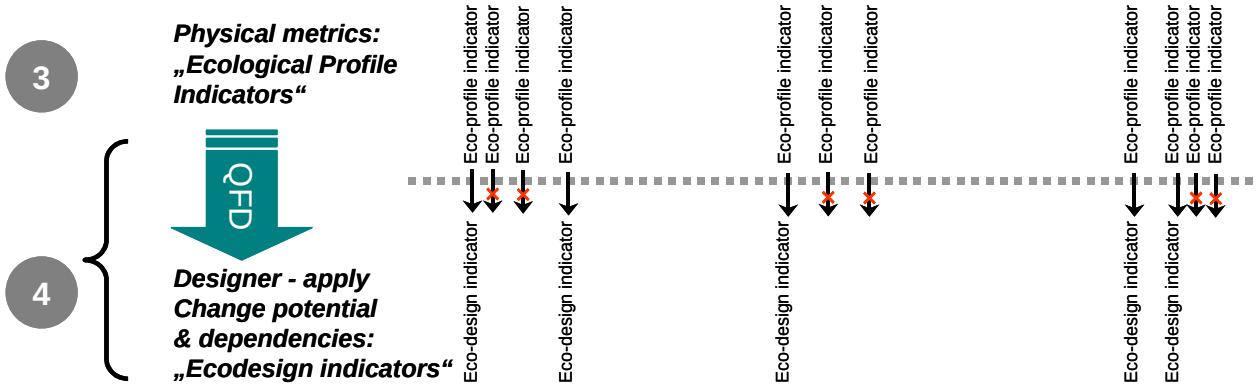


Figure 9: Step 4: Identification of product (group) specific Eco-Design Indicators

In order to take the designer's options into account, close cooperation is needed. For the baseline study (desktop computer) within this project the following questions are posed exemplarily:

1) Which components can be practically changed in which range? E.g.:

- Is it possible (of course in dependence of the regarded product) to reduce the size of the PWB? What are the tendencies in future (e.g. more layers, less size,…)
- How can and will amount and kind of IC's change (e.g. more high-integrated IC's, but overall less IC's)
- Which subassemblies can be influenced by the OEM and which not?

2) What are dependencies between design changes? E.g.:

- Less/other IC's and components on the PWB might lead to size reduction of the PWB

Especially within this project five major known dependencies per Ecological Profile Indicator are defined, but also an extension of the amount is possible. The value of the dependency has to be defined which means how much does the interrelated Ecological Profile Indicator change in percent if there are a dependency with another Indicator. The consideration of the change potentials and the major known dependencies leads to a reduced number of Ecological Profile Indicators. These Eco-Design Indicators are identified with an adapted QFD-approach.

In the following graph the QFD-approach is explained. The adapted QFD-approach of the EPIC-ICT Method is based on the general QFD Method. The structure and the format are nearly the same. The 'WHAT' are in the adapted approach the chosen impact categories and the toxic relevant flows, identified in step 3. The 'HOW' are the values of the change potentials of the identified Ecological Profile Indicators and the 'Correlation of HOWs' are the major known dependencies of the Ecological Profile Indicators. Connecting these module deliver a list of Eco-Design Indicators.

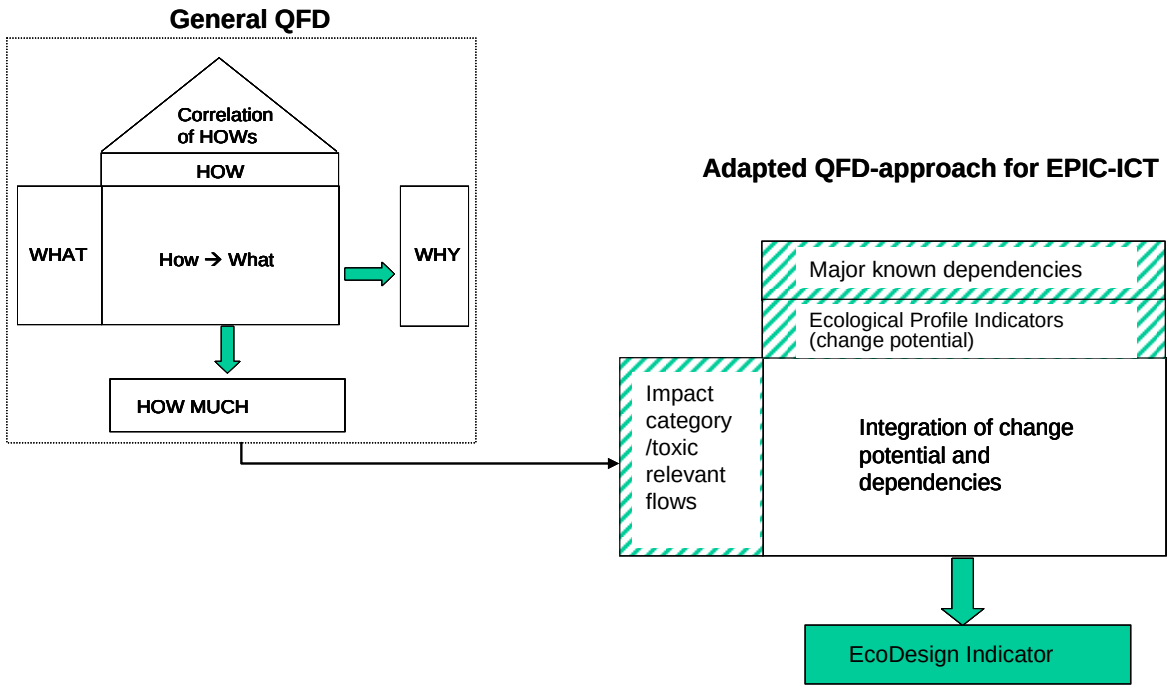


Figure 10: Adapted QFD-approach for the EPIC-ICT Method

The Eco-Design Indicators consider the same selected impact categories and toxic relevant flows as for the Ecological Profile Indicators. At least in one impact category

or in one toxic relevant flow the Ecological Profile Indicators is represented to be used identifying an Eco-Design Indicator. For all relevant Ecological Profile Indicators LCA results for the respective categories are carried out. The Eco-Design Indicators are based on the Ecological Profile Indicators.

There exist different possibilities of getting Eco-Design Indicators. The Eco-Design Indicators results only if a change potential is identified, otherwise it is no Eco-Design Indicator. Is the Ecological Profile Indicator technical and economic changeable but without dependencies with another Ecological Profile Indicator then a positive Eco-Design Indicator results. In case of technical and economic changeable but with dependencies then the Eco-Design Indicator can be positive or negative. A special case is if there is a technology shift (technical and economic changes) of the product then an update of the model is necessary.

Within this project Generic Modules are used to build up the LCA model. With these Generic Modules it is easy to consider Design Indicators. It would be more effort to consider changes of the product without a parameterized, flexible model structure such as the Generic Modules generates. Considering an LCA model without Generic Modules the changes of Design Indicators can only be analyzed by creating new assemblies. The analysis format for identifying Ecological Profile Indicators respectively EcoDesign Indicators has to be updated, which might be more time intensive – depending on the scope of the change.

As results of the steps 1 to 4 the EPIC-ICT Method delivers on the one hand a list of Ecological Profile Indicators and on the other hand a guidance for identifying EcoDesign Indicators (including the change potential and the partly subjective decision of major known dependencies).

4.2.1 Eco-Design Indicators at the example of the PC

As described above, for this step the identified Ecological Profile Indicators have to be checked for change potential and dependencies. The respective values are presented in the following Table 5 exemplarily for the main values (for the PC, no dependencies exists, so the “roof” is empty).

Dependencies

	Production									Use
	PWB Assy		Memory Assy			CPU	Connectors			
	FR4 (m2 Fr4 size)	Processor north/southbr. (m2 die size)	PWB FR4 (m2 FR4)	Memory IC's (m2 die size)	Gold plating (kg gold)	m2 die size	Gold plating (kg gold)	EMS shielding (kg EMS sheet)	PBT granulate (kg PBT)	Min mode (kW power demand x hours)
Change potential	10%	0%	0%	25%	100%	0%	100%	5%	5%	20%
Primary Energy [MJ]	50	0	0	5	9	0	27	0	0	1502
CML2001, Acidification Potential (AP) [kg SO2-Equiv.]	2,E-02	0,E+00	0,E+00	5,E-04	1,E-02	0,E+00	3,E-02	4,E-04	4,E-05	3,E-01
CML2001, Eutrophication Potential (EP) [kg Phosphate-Equiv.]	7,E-04	0,E+00	0,E+00	3,E-05	4,E-04	0,E+00	1,E-03	2,E-06	4,E-05	2,E-02
CML2001, Global Warming Potential (GWP 100 years) [kg CO2-Equiv.]	2,51	0	0	0,10	0,81	0	2,32	0,00	0,02	66,71
CML2001, Ozone Layer Depletion Potential (ODP, steady state) [kg R11-Equiv.]	5,E-07	0,E+00	0,E+00	2,E-08	2,E-08	0,E+00	6,E-08	1,E-09	3,E-09	2,E-05
CML2001, Photochem. Ozone Creation Potential (POCP) [kg Ethene-Equiv.]	1,E-03	0,E+00	0,E+00	7,E-05	6,E-04	0,E+00	2,E-03	2,E-05	1,E-05	2,E-02
....										

Table 5: Eco-Design Indicator generation

The analysis leads to the following new order when switching from Environmental Profile Indicators to Eco-Design Indicators, according to the relevance of the respective module considering all the modules mentioned here. Table 6 gives the relative contribution of the indicators of Table 5 by relating them to the total environmental impacts of all indicators in Table 5, so the contribution of the indicators is given in percent instead of absolute numbers.

	Production									Use
	PWB Assy		Memory Assy			CPU	Connectors			
	FR4 (m2 Fr4 size)	Processor north/southbr. (m2 die size)	PWB FR4 (m2 FR4)	Memory IC's (m2 die size)	Gold plating (kg gold)	m2 die size	Gold plating (kg gold)	EMS shielding (kg EMS sheet)	PBT granulate (kg PBT)	Min mode (kW power demand x hours)
Primary Energy [MJ]	3,2%	0,0%	0,0%	0,3%	0,6%	0,0%	1,7%	0,0%	0,0%	94,2%
CML2001, Acidification Potential (AP) [kg SO2-Equiv.]	4,8%	0,0%	0,0%	0,1%	2,6%	0,0%	7,3%	0,1%	0,0%	85,1%
CML2001, Eutrophication Potential (EP) [kg Phosphate-Equiv.]	2,8%	0,0%	0,0%	0,1%	1,6%	0,0%	4,5%	0,0%	0,1%	90,8%
CML2001, Global Warming Potential (GWP 100 years) [kg CO2-Equiv.]	3,5%	0,0%	0,0%	0,1%	1,1%	0,0%	3,2%	0,0%	0,0%	92,0%
CML2001, Ozone Layer Depletion Potential (ODP, steady state) [kg R11-Equiv.]	2,6%	0,0%	0,0%	0,1%	0,1%	0,0%	0,3%	0,0%	0,0%	96,9%
CML2001, Photochem. Ozone Creation Potential (POCP) [kg Ethene-Equiv.]	4,8%	0,0%	0,0%	0,3%	2,0%	0,0%	5,6%	0,1%	0,0%	87,3%

Table 6 Eco-Design Indicator relevance (highest value per category highlighted)

1) Use phase: MIN mode [kW power x hours MIN mode]
2) Connectors: Gold plating [kg Gold]
3) Mainboard: size of the FR4 PWB [m^2 FR4]
4) Memory assembly: gold plating [kg gold]
5) Memory assembly: size of the dies [m^2 die size]
6) Connectors: EMS shield [kg EMS shield]
7) Connectors: PBT plastic granulate [kg PBT]

The die size of the processor, the size of the PWB of the memory module and the die size of the north/southbridge vanished completely, as the change potential was rated with “0” (see Table 5).

5 Method application: Technology shifts

A further requirement of the method is the ability of involvement of technology shifts corresponding with environmental results as effects from technology shifts. Technology shifts by definition are changes of parts, components or technologies, which go beyond a mere progress or trend in developments. Often it is set by a cut in kind of descending of an established technology and rise of an exchanging entirely new technology. Examples are records, CDs and dematerialised mp3 storage media or the shift from CRT to plasma and TFT monitors.

With view on the description of the method in the chapters it becomes obvious that almost all components, parts and (sub-) assemblies can be implemented. Pre-requisite is the respective knowledge of the technology in order to be able to implement technological interdependencies, definition of materials, manufacturing processes and other relevant information, which define the part or technology sufficiently.

If a technology shift “happens”, a respective LCA model (preferred using the Generic Modules) is required in order to implement environmental effects of the technology shift within step 2, 3 and 4. Simply those data have to be changed, which affects changes by the new technology. Step 3 and 4 have to be re-calculated with the new values reflecting the technology shift. A possible change in the indicator ranking shows the effects caused from the technology shifts.

It shall be clearly pointed out here that there is no method to calculate or estimate technology shifts before the respective technology exist and is close to a market introduction. It should be clear that things that do not exist can also not be correctly assessed concerning their environmental impacts[1].

Also predictions of possible effects from coming technology shifts (or further developments) can be carried out. But fundamentally for the feasibility of those calculations is the existing knowledge of technological details, such as material decisions, manufacturing processes and technological aspects, in order to be able to define Generic Modules sufficiently. The presented method is not able to be applied as an invention tool, which might develop technology shifts or calculate effects of not yet existing parts, products or technologies.

[1] Remark: This statement reflects the opinion of the consortium. It does not necessarily represents the position of the European Commission on this topic

Therefore chapter 5.1 and 5.2 define technologies and existing as well as anticipated technology shifts, which for example could be taken into consideration with the presented method.

5.1 Future Trends for main assemblies

	Short term	Impact	Long term	Impact
Computer System (general)	- Multimedia-zation of home-based computer systems: replacement of conventional hi-fi devices as CD-/DVD-player, Radio, TV-set, video recorder with easy to operate Multimedia-PCs		- Network of multiple connected computer systems (partially embedded in other devices like air conditioning systems, fridges) to control lighting, heating/cooling, frigde content, calorie consumption, incoming calls, emails, and visitors, and much more…	
	- systems are fully loaded with functions		- Miniaturized and custom-designed computer systems emerge for these tasks	
			- Classical PC-Towers will only be used as Game-PC's of enthusiasts whose can upgrade it to most current state of the art	
Motherboard	- Main form factor is ATX with trends to smaller form factors	O	- The form factor is custom based and minimizing	++
			- Reduction of front side bus clock rate in idle states	+
Processor	- Power consumption is raising with increased performance,	--	- Highest goal will be to minimize power consumption, in idle-mode as well as under full load	++
	- increasing of clock rate will be replaced by adding more functions and cores to the CPU to reach a higher performance	+	- performance of the cpu (and whole system) will be measured in performance/watts	++
Graphic Card	- trend to multiple graphic cards and/or graphic cards with multiple GPUs especially for enthusiasts; in this case heavy cooling effort is necessary	--	- graphic cards are only important for gamers and professional movie editors for HDTV-editing, for all other applications the GPU will be integrated into the chipset or embedded on the motherboard	o/+

	- for multimedia applications graphic processing will be integrated in the chipset	+	- the trend to minimize power consumption is similar to the CPUs	++
			- power saving functions implemented for idle/part load states	++

	Short term	Impact	Long term	Impact
Physics Card	- a physics processor will appear in gaming pc's	--	- a physics processor card is fixed part of gaming systems	-
HDD	- Storage space further increases	O	- HDD will be replaced by non-mechanical storage devices such as flash-memory with high data transfer rates	++
	- HDD will be equipped with flash memory to reduce accesses and power consumption	+	- New storage devices will be developed deploying quantum technology for example	?
RAM	- the DDR memory will be replaced by DDR2 and DDR3 with reduced operating voltage resulting in lower power consumption at higher bandwidth	+	- The volatile memory will be replaced by non-volatile high-speed/-bandwidth memory such as ferromagnetic RAM to significantly reduce power consumption	+
Removable Storage	- Current Optical drive standards will be replaced by new techniques such as Blue Ray with higher storage capacity per disc	O	- Optical storage discs could be replaced by long lasting biodegradable discs	++
	- Consumption of recordable optical storage media for data transport will be reduced by broader usage of high capacity USB-memory sticks	+		
PSU	- No groundbreaking technology shift appearing	O	- Power saving features for part load controlled by system may be implemented	++
	-		- Reduction of stand-by power consumption	+
Display	- CRTs will be replaced by TFT-displays	+	- TFT-displays will be replaced by OLED-displays	++
	• TFT-displays will be deployed with LED-backlighting	+		
Printer	?		?	

Motherboard

At present the main form factor of desktop motherboards is ATX. In short term there is no change in size recognizable but an increasing functionality of the board, which means more integrated functions (WLAN, WiMAX, Graphics…).

The slot count for extension cards or memory modules will be unchanged but the bus standard may change (PCIe -> PCIe / DDR-> DDR2->DDR3).

For the long term a customization of the board for the respective use will be accompanied by minimization. All necessary functionality will be integrated in the board (HDTV acceleration, -de-/encryption, communications). Maybe a power saving mechanism will be introduced to decrease the front side bus clock rate in idle states. This will achieve a reduction in power consumption of the motherboard (esp. Chipset(s)) and the memory-modules.

CPU

Presently the power consumption of a CPU for mainstream and high-end desktop systems ranges from below 60W to above 120W. In short term this will continue to grow partially. There is a trend recognizable, that there are “normal performers” for the mainstream market with slightly decreasing power consumptions while increasing functionality and also performance. These CPUs are single or lower clock rate dual core units. On the other hand there are the high end processors with increasing typical power consumption for an increasing clock rate. These CPUs are only dual core units with typical power consumption of 100W and above. To broaden the bandwidth the pin count is increasing and so the size of the CPU. The die size will be unchanged despite shrinks of the processing core with shifts to newer process technologies. The increase of cache size is compensating these core size savings. The manufacturers will concentrate their development of new CPUs on power efficiency.

In long term the power consumption will not increase further, achieved by new process technologies and power saving mechanisms. The power saving functionality will be optimized to minimize power consumption in idle state. Processors will be more application focussed which means that the CPUs are customized for its respective use. For example a processor for a home multimedia system has not to perform on the highest edge; the most important is a high bandwidth to play and compress-/decompress HDTV videos. This CPU has maybe 4 cores all active on full clock rate when compressing-/decompressing. When playing a HD-DVD video only one core is active on half the clock rate and this the most part of the time.

HDD

The current Longitudinal-Recording-Technology will be replaced by the Perpendicular Recording Technology. This means higher data density on the platter and therefore higher capacity of the Hard Disk Drive (HDD). Another phenomenon will be a slow transition from 3,5” to smaller 2,5” HDDs which can’t offer a very high capacity and furthermore they are slower. But on the other hand they are very quiet, space and power saving. So they are most suitable for small media systems or internet access points and servers.

In long term HDDs in general will be replaced by Solid state drives without platter and so without any rotating parts. They consist of static memory such as Flash or Ferromagnetic RAM (FRAM).

The benefits of this technology shift are a significant lower power consumption, longer lifetime and noiseless operation. In future the quantum technology may be deployed as storage method amongst others.

RAM

The currently common DDR, DDR2 memory will be replaced by DDR3 with a reduced operating voltage resulting in lower power consumption at higher data throughput.

In long term the volatile memory will be replaced by non-volatile high-speed/-bandwidth memory such as ferromagnetic RAM to significantly reduce power consumption.

Graphics card

In short term there it is recognizable a trend towards multiple graphic cards and/or graphic cards with multiple GPUs especially for enthusiasts. For that case heavy cooling effort is necessary and will consume more power.

In long term graphics cards will become only important esp. for gamers and professional movie editors for HDTV-editing. For all other applications the GPU will be integrated into the chipset or embedded on the motherboard. There is also the trend predictable to minimize power consumption, similar to the CPUs. Part of it will be the implementation of power saving functions for idle/part load states.

Sound Card

There no significant trend predictable. It should be wished from the motherboard designers to implement higher quality sound chip on its board with are dedicated to

multimedia systems. Also the connections and noise sensitivity should be improved in future generations to avoid additional sound cards.

Optical Drives

Current Optical drive standards will be replaced by new techniques such as Blue Ray with higher storage capacity per disc. Optical storage discs could be replaced by long lasting biodegradable discs in a long term perspective.

Connectivity

Today the wired connectivity has the majority in communication standards. They will be completed and partly replaced by wireless communication standards. In short term a large number of wireless connectivity solutions and standards are implemented in the computer system such as LAN, WLAN, WiMAX and Bluetooth. Today it is necessary to use a plug-in card for each wireless communication standard. In near future all common wireless standards will be supported by the motherboard. In long term view the very most (home entertainment, communication and office) devices communicate seamless with each other wireless without the need to install drivers or something else.

Chassis

As recognizable by now the case of the computer systems will have a customized style. Multimedia systems will look like multimedia systems: slim, stylish and noble. Gaming systems in contrast will look like gaming consoles. The current white box design will never again appear. In the future the computer will disappear from our eyes; they will be integrated in displays, furniture and the like.

PSU

In future PSUs a reduction of stand-by power consumption should be achieved.

Cooling System (CPU, [GPU])

The massive heat sink bodies of today’s CPU cooling systems will be replaced by heat pipe systems. At this time there are a lot of future technologies in development: A famous one is the replacement of the water in the pipes with special liquid metal alloys.

6 Summary and conclusions

As shown in the chapters before, the EPIC-ICT consortium succeeded in proposing a clear and structured methodology and guideline to systematically analyze products and derive the environmentally best design option under consideration of technical necessities either depending on customer demands or technical/economic reality to the commission.

The derived Eco-Design Indicators reflect physical product properties and are therefore easy to understand for product planners and designers. So this method closes the gap between environmental experts and practitioners. These Eco-Design Indicators can therefore be applied easily in practice, guarantee environmental progress without hindering technical development and are suitable for politics to define and control environmental goals.

In order to reflect changes in technologies and product characteristics, it is proposed to update the procedure (including the detailed LCA) in accordance with the product development cycles. These differ between the product groups. For personal computers it is proposed to update the study every 3 – 4 years. This shall ensure that technical development is considered and that the application of the indicators does not hinder technical development.

In general, within the EPIC-ICT framework it is not necessarily needed that every producer carries out an LCA study for its respective products. It is rather suggested that the results from a full-scale and detailed LCA study, consistent with the requirements on data and representativeness, are used by a group of interested stakeholders.

The representativeness of the results of LCA study is mainly defined in the product definition and needs to be evaluated by sensitivity analyses. These analyses – very much facilitated by using parameterized product system models - of variations point out the boundaries of the study and with this the scope of application of the resulting Environmental Performance Indicators.