Key Environmental Performance Indicators (KEPIs): A New Approach to Environmental Assessment

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Abstract

A new Key Environmental Performance Indicators (KEPIs) approach has been developed considering the perspective of a designer who may like to improve the environmental performance of the products but has limited resources and understanding of complex environmental terms. This approach empowers the designer with indicators like the area of PWB, the amount of precious metals etc which account for the physical and chemical characteristics of the product and its components. The indicators can be used for setting guidelines, benchmarking, monitoring and improving environmental performance. These indicators are easy to use, and require little time and data for assessing the environmental performance. The approach greatly reduces the reliance on the product chain for gathering of data and allows the manufacturers to make big leaps, in improving the lifetime environmental performance of the products, on their own.

1 Introduction

The manufacture, usage and disposal of the electronic products causes several environmental impacts like resource depletion, global warming, air pollution, eco-toxicity, etc. To manage its environmental performance, the electronics industry has mainly used Life Cycle Assessment (LCA) as a tool. Though LCA is a proven, scientific and reliable method, it has limitations in terms of resource requirements and applicability during the initial stages of product development. It also relies heavily on the cooperation with the suppliers and other stakeholders in the product chain for the collection of data. Moreover, the results from LCA are classified in several impact categories like ozone depletion, acidification potential etc which are difficult for a designer to relate to.

This study was commissioned by Motorola, Nokia, Panasonic Mobile Communications and Philips to develop a new simple approach to assess and improve lifecycle environmental performance of the mobile phones. The KEPIs approach was developed considering the perspective of a designer who may like to improve the environmental performance of the products but has limited resources and understanding of complex environmental issues.

This approach empowers the designer with indicators that account the physical and chemical characteristics of the phones and its components. These indicators can be used for setting internal guidelines, benchmarking, monitoring and improving environmental performance. These indicators are easy to use, and require little data and time for calculation.

2 Discussion on environmental indicators

Indicators can be developed for several purposes, the chief being benchmarking, monitoring and reporting environmental performance. The ISO 14031 standard[1] provides guidance on developing indicators for the environmental performance monitoring and reporting purposes. It suggests two broad categories of indicators a) Environmental Performance Indicators (EPIs) and b) Environmental Condition Indicators (ECIs). The EPIs focus on the environmental aspects like energy consumption, water consumption etc. whereas the ECIs focus on the environmental impacts and include indicators like air and water quality parameters.

Though these indicators are very useful for the purpose of assessing the environmental performance, they do not provide much guidance to the product designers in the industry. The product designers, who generally have little know-how of the environmental issues, desire to have indicators which relate the physical and chemical characteristics of the products to the environmental impacts. As it is difficult for a product manufacturer to have a thorough control over the processes of its suppliers altering the physical and chemical characteristics of the product during the design stage, to improve its environmental performance, is a wise strategy.

There are two principal ways in which the environmental indicators can be developed based on their end use. These two ways generally correspond to the use of the indicators by either the environmental manager, who is interested in demonstrating the environmental performance of the industry, or the product designer whose aim is to improve the environmental performance of the products by changing its characteristics.

Indicators for Environmental Managers	Indicators for Eco-designers
Account the environmental aspects and impacts of products	Account the physical and chemical characteristics of product
Main objective is to demonstrate environmental performance	Main objective is to use them for eco-design, benchmarking, monitoring
Can be used both for internal and external communication	Can only be used for internal communication
Input-output information needs to be sourced from suppliers	Information on physical and chemical characteristics of the components needs to be sourced from suppliers
Life Cycle Inventory (LCI) is to be maintained	No LCI is required
Examples include water consumption, toxicity potential, resource depletion potential etc.	Examples include size of PWB, quantity of precious metals, amount of lead etc.

Table 1: Types of Environmental Indicators

The purpose for which the indicators are to be used determines the kind of indicators that are to be developed. For the purpose of improving environmental performance, the indicators on the physical and chemical characteristics of the product should be developed whereas for the purpose of monitoring and external reporting the indicators on environmental aspects and impacts should be developed.

3 Characteristics of the indicators

The following characteristics were considered for developing the indicators:

- They shall have a scientific base.
- They shall be mutually exclusive and collectively exhaustive in considering the life cycle environmental impacts.
- They shall be easy to use and understand.
- They shall require little time and costs for their calculations.
- They shall give reliable results.
- They shall be applicable in all geographic regions.
- They shall be easy to extend to other electronic products.
- They shall provide clear-cut guidelines to the designers and require no interpolation from the environmental impacts.

4 Methodology

To develop the indicators for use by designers, it was necessary to identify the environmentally relevant components and significant materials in the phone. For this purpose, two different perspectives i) the LCA perspective and ii) the legal perspective were used. The environmentally relevant components were further analysed to identify the physical and chemical characteristics that influence their lifecycle environmental performance. The most crucial chemical and physical characteristics of the mobile phones and its components are proposed as KEPIs.

5 LCA perspective

The results specified in the several impact categories of LCAs conducted by the participating companies were examined to identify the environmentally relevant components. These impact categories include energy consumption, global warming potential, acidification potential, ozone depletion potential, photochemical oxidant potential, human toxicity potential, resource depletion potential and air pollution. New Eco-indicator 99[2] assessments were also conducted to identify the significant materials and the relevant components. The main assumption in using the LCA perspective was that though the LCAs may not give accurate results they do correctly point out the source of majority of the impacts.

5.1 Analyses of LCA impact categories

5.1.1 Energy consumption

The LCAs conducted by Motorola[2], Nokia[3] and Panasonic Mobile Communications[4] for mobile phones have yielded similar results in terms of energy consumption if the same lifetime and user scenario are considered. The production phase accounts for over 50% of the consumption whereas the usage phase accounts for approximately 40% if a life time of two years is considered. The production phase encompasses the raw material acquisition, component manufacture and product assembly. The *standby power consumption of the charger* in the usage phase accounts for a big proportion of energy consumption. *PWB* is the most relevant component in the phone consuming significant amounts of energy during production. *ICs*, which follow PWBs, also consume significant amounts of energy during production. *LCD* consumes relatively lesser amounts of energy in the production phase.

5.1.2 Global warming potential

The results of the LCAs conducted by Nokia and Panasonic Mobile Communications are very similar for global warming potential (GWP) of the phone. The production and the usage phase have similar contributions of over 40% to the GWP. The most relevant component in the phone according to both the studies is the *PWB*. The *ICs* and *LCD*, which also have a considerable GWP, follow PWB. The *standby power consumption of the charger*, under the usage phase is another crucial contributor.

5.1.3 Acidification potential

The analyses of the LCA results points out the differences in the studies by Nokia and Panasonic Mobile Communications in this impact category. The Nokia study identifies production as the most relevant phase in contrast to the usage phase identified by Panasonic Mobile Communications. This contrast is attributed to the differences in the user scenarios and the markets of the phones. The studies yield similar results in identifying the *PWB* as the most significant contributor to the acidification potential. The *standby power consumption of the charger* is also a big contributor. The *ICs* and *LCD* follow PWB and are worth considering. *Copper present in the cables of the charger* also has a significant acidification potential.

5.1.4 Ozone depletion

The analysis of the Ozone Depletion Potential (ODP) impact category from Nokia's LCA identifies the *solder paste* as the most important contributor. The presence of tin and silver in the solder is responsible for its high ODP. *PWB* is the next most important contributor to the ODP. No other components have significant contribution.

5.1.5 Photochemical oxidation potential

Nokia's LCA identifies *solder paste* as the most important contributor to the photochemical oxidation potential (POCP). The metals tin and silver are responsible for the high POCP of the solder paste. The PWB follow solder paste but its contribution to POCP is little in comparison.

5.1.6 Human toxicity potential

The analysis of human toxicity potential (HTP) from Nokia's LCA identifies production phase as the most crucial phase with *PWBs* as the biggest contributors to HTP. The connectors follow PWBs and are also significant contributors to HTP of the phone due to the presence of gold in them. The ICs contribute relatively little to the HTP of the phone.

5.1.7 Resource depletion potential

According to the LCA by Panasonic Mobile Communications, *LCD* is biggest contributor to resource depletion impacts. *Copper and its alloys (especially with zinc) used in the cables of the charger* also contribute significantly to resource depletion impacts. The *standby power consumption* of the charger is another major contributor.

5.1.8 Air pollution

The air pollution impact category from Panasonic Mobile Communications's LCA identifies *standby power consumption of the charger* as the most important contributor to air pollution. The *air freight* of the products is another big contributor to air pollution. *Copper and its alloys used in the cables of the charger* also account for a fairly large percentage of air pollution impacts.

5.2 New Eco-indicator 99 Assessments

5.2.1 Life cycle impacts of a mobile phone

The Eco-indicator 99 assessment for a few late ninety mobile phone models was carried on a rough scale with the sole purpose of identifying the environmental priorities. According to the assessment the production phase accounts for majority of the life cycle impacts and is followed by the usage phase. The production of *populated PWB* accounts for approximately 90% of the impacts from the production phase. The presence of gold, in the semiconductors and the finishes of PWB, is responsible for the environmental relevance of populated PWB. LCD has little contribution to the total environmental impacts of the phone according to this assessment. In the case of charger, copper accounts for most of the impacts from its production phase.

5.2.2 Disposal phase of the mobile phone

The disposal phase has negligible contribution to the environmental impacts during the life cycle of the phone as observed from LCAs conducted by Nokia, Motorola, and Panasonic Mobile Communications and Eco-indicator 99 assessments of old mobile phones. The disposal phase becomes important when the positive environmental aspects of the recovery of precious metals are considered[6].

The Eco-indicator 99 analyses of a few 2002-2003 phone models brings out that *the recovery of gold alone in the disposal phase has the potential to offset over 83% of the impacts from the raw material acquisition phase*. If all the metals and the energy from the incineration of the organics are recovered then approximately 88% of the impacts from raw material acquisition phase can be offset. The recovery of the precious metals, especially gold, from the populated PWB is crucial to offset the environmental impacts. The incineration or the recycling of the plastics has negligible contribution in offsetting the impacts.

The profitability of recycling phones is dependent on the amount of precious metals they contain. An optimal amount of precious metals should be present in the phone to make it economically feasible and financially attractive for the recycler to recycle the phone and offset as much environmental impacts as possible. Further to this, there is another practical argument which accounts the very low percentage of mobile phones that are recycled world-wide. One of the main reasons for this low percentage is the consumer reluctance to dispose of the phone. Considering these arguments, it is advised that when recycling is not occurring, the amount of precious metals especially Gold should be minimised and when recycling is an option, an optimum amount of precious metals should be maintained.

6 Legal perspective

The legal perspective was used to identify the environmentally significant materials in the phone which account for its embedded toxicity. The Green Design Advisor[7] (GDA) tool of Motorola was used for this purpose. GDA accounts the product Toxicity Index for assessing the toxicity. The index, developed by Motorola, is based on hazardous substance legislation presently effective in Europe and reflects the strict standards of the PTT Telecom, Netherlands, and Deutsche Telekom, Germany. The measurement “unit toxicity” has a value of 1000 for the most highly regulated substances that have a limit of 50 ppm. The higher the ppm value the lower the unit toxicity value. The component toxicity index is the product of the unit toxicity value of each substance contained in the component and the total mass of the component.

6.1 GDA results

According to the GDA analysis, the *populated PWB* is responsible for over 75% of the phone’s toxicity. It is followed by the *LCD assembly* (PWB, display, flex), which has very low significance in comparison to it. *Bromine* is the most significant material and accounts for most of the embedded toxicity of the phone components. *Lead* is the next important contributor to embedded toxicity of the phone. Bromine has lower toxicity index than lead but due to its presence in higher quantities it becomes more significant. For the phones, which were analysed, the mass of lead varied between 35-55% of the mass of bromine.

7 Eco-indicator 99 assessments of relevant components

The *PWBs, Semiconductors, LCD* and *Solder* were identified as the most relevant components from the LCA and the legal perspectives. These components were further examined to identify their physical and chemical characteristics that have a significant bearing on their environmental impacts.

7.1 PWBs

For a PWB, the raw material acquisition phase and the manufacturing phase account for approximately 70% and 30% of the life cycle environmental impacts respectively. The Eco-indicator 99 analysis identifies *gold* as the most significant material in the raw material acquisition phase. It is followed by copper, epoxy and ceramic. The environmental impact of PWB varies with the intensity of the precious metals especially gold. Gold is present in minute quantities in the finishes and is negligible in comparison to the masses of the other materials. The impacts from the manufacture of PWB are directly proportional to the *number of layers and its area*. The amount of gold and the total area (multiple of surface area and number of layers) are proposed as the key indicators.

7.2 Semiconductors

Three different types of semiconductors namely modules, discrete semiconductors, and integrated circuits were examined by Eco-indicator 99 to identify their environmental impact distribution.

For the modules, the *gold wires* account for over 50% of the life cycle environmental impacts if only the raw material acquisition and manufacturing phases are considered. The presence of *platinum* in the substrate accounts for approximately 30% of the life cycle impacts.

In the case of discrete semiconductors, the *gold wire* in the packaging has the highest contribution followed by the *fabricated die* and the lead frame. The presence of copper in the frame accounts for over 99% of its impacts.

For the integrated circuits, the *gold wire* in the package accounts for approximately 70% whereas the *fabricated die* is responsible for over 20% of the life cycle impacts. Over 90% of the impacts of the fabricated die arise from the processing of the input wafer. The impacts from the wafer processing are linked to the *number of mask steps and the area of the die*. The amount of gold in the semiconductors and the area of the fabricated dies are proposed as the key indicators.

7.3 LCD

The environmental impacts arising due to the materials in LCD are insignificant when compared to the impacts from the manufacturing phase. The *manufacturing phase of LCD accounts for over 85%* of the life cycle environmental impacts if the usage phase is not considered. The analyses of LCDs indicate that the electricity consumption accounts for over 65% of the 85% impacts from the manufacturing phase. The environmental impacts of the LCD are in direct proportion to its *area*. Thus, the area of the LCD is a good indicator of its environmental impacts.

7.4 Solders

The environmental impact distribution for solders of different composition was similar, with raw material acquisition phase accounting for over 90% of the impacts. The impacts of the solders are attributed to metals like *tin, silver, copper and zinc* present in them. The manufacture of the solders has little contribution to life cycle environmental impacts. Thus, a reduction in the amount of solder used in the phones will lead to better environmental performance.

8 Proposed indicators

Following indicators were proposed for assessment and evaluation of life cycle impacts of the mobile phones. The relative importance of the indicators is marked by a leaf sign (♠). The more the number of leaves in front of the indicator the more important it is. The allocation of leaves to the indicators is based on the observations made by the author during the course of this work.

Production Phase

- Amount of precious metals specifically *Gold* ♠♠♠
- Total area of PWB (Surface Area x No. of Layers) ♠♠♠
- Areas of the fabricated dies which are processed with the same number of mask steps♠♠♠
- Amount of bromine ♠♠
- Area of the LCD ♠♠
- Amount of solder paste ♠
- Amount of copper used in charger and its cables ♠

Transportation Phase

- Number of components in the phone (No two components are transported in the same package) ♠

Use Phase

- Standby power consumption of the charger ♠♠♠

The designers should aim at reducing the values of these indicators to improve the lifecycle environmental performance of the mobile phones. However, circumstances may arise when the designer may not be able to reduce the values of the above mentioned indicators due of certain limitations for example customers' desire for a larger LCD. In such a case the designer should focus on the environmental aspect that the indicator is limiting. For example, in the case of LCD the designer should focus on the energy consumption during the manufacturing of the LCD.

9 Test of indicators

The KEPIs were subjected to an independent test to assess their resource requirements and applicability to other electronic products. The indicators were tested for a desktop PC and a notebook PC having similar functions and lifetime. The results of the indicators were assessed against the results of LCAs conducted by a Japanese corporation for the same products.

The results from KEPIs were in conformity with the LCA results suggesting that they are reliable to use.

The data required for KEPIs, to identify which PC has better environmental performance than the other, was negligible when compared to the data requirements of LCAs. It took just three days to gather the required data for analysing the PCs using KEPIs. These three days included contacting, requesting and receiving data from the Japanese corporation. Once the data was received it took a few hours to analyse it and conclude that the notebook PC had better environmentally performance than the desktop PC.

10 Guidelines for using KEPIs

KEPIs can only be used to compare the environmental performance of products which serve the same function(s) and have the same life-time. For example, a mobile phone X may not have a better environmental performance than mobile phone Y even if the KEPIs suggest so. The reason behind this may lie in the fact that the mobile phone Y has additional capabilities of a PDA which are not possessed by phone X. Thus, the mobile phone Y creates a substitution effect for a PDA unlike phone X. The phone X is environmentally better than phone Y if and only if the functional use of two-way communication by talking and the same life-time is considered.

The following steps are suggested for using KEPIs:

1. Define the products/alternatives which need to be evaluated or compared.
2. Identify the functions that these products/alternatives serve. Identify the common function(s) against which the environmental performance is to be assessed.
3. Identify the life-time of the products/alternatives.
4. Gather the data required for calculating the KEPI values for the selected products/alternatives.
5. Calculate the values of the indicators using the data gathered.
6. Identify which product/alternatives have better environmental performance. The product/alternative with lower values for all KEPIs must have better environmental performance. Sometimes the values for some KEPIs may be higher whereas for others they may be lower. In such a case, designer should make a decision based on his logic and by using the ratings (♠) of the various indicators as a weighting factor.

11 Literature

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