Life Cycle Assessment – Looking at Powerformer™

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Apart from its broader significance for society, environmental performance can also affect how successful a product will be in the marketplace. Because of this, suppliers need to be able to reliably describe and quantify the environmental impact of every stage in a product's life cycle, from extraction of the raw materials, through the product's manufacture and use, to its being taken out of service and disposed of. Life Cycle Assessment (LCA) is a method used by ABB to develop environmentally compatible components and systems. LCA ensures not only clean, efficient methods of production and materials that can be reused and recycled, but also designs that emphasize high efficiency in service. For electrical products in particular, since they 'leak' electricity into the surroundings, it is the utilization phase that takes the greatest toll on the environment over a product's lifetime. LCA comparison of the environmental impact of Powerformer™, ABB's new high-voltage generator, with a conventional system, points up the suitability of this method for a wide range of other products.

While man's impact on his surroundings has increased throughout history, it was with the advent of the industrial revolution that environmental problems as we know them today first became widespread. Then and for a long time afterwards, poor eco-sense meant that the consequences of dumping effluents and waste products in landfills, etc, were not foreseen. In fact, it was not until quite recently that environmental concerns began to get the public attention they deserve.

Gradual development

Ecological awareness has grown slowly, with society moving progressively from the casual discharge of polluted industrial water and waste gases into the environment to the multi-stage treatment and reduction of emissions in evidence today. Over the same period, focus has shifted from the production processes to the products themselves and to their use.

Local environmental problems have developed into global ones, since, broadly speaking, they affect the entire world – its inhabitants and its animal and plant life. The problems therefore have to be solved on a global level, necessitating cross-border co-operation.

In 1972, the first environmental conference, arranged by the UN, was held in Stockholm. Global environmental work did not begin in earnest, however, until 1983, when the UN General Assembly set up the 'The World Commission on the Environment and Development', also called the Brundtland Commission after its chairperson, the Norwegian prime minister, Gro Harlem Brundtland. In 1987, the commission presented the report, 'Our Common Future', in which the concept of 'sustainable development' was expounded. Sustainable development is defined as 'Social progress that meets the needs of the present without compromising the ability of future generations to meet their own needs'. The report deals with changes and opportunities for development. Trade and industry are given the responsibility of altering processes and products to fit in with nature.

The next big step was the UN's 1992 world conference in Rio de Janeiro, where a global action plan for sustainable development, Agenda 21, was formulated. This agenda for the 21st century is addressed to states and individuals, to organizations, to trade and to industry, and calls for participation in working towards a wholesome environment.

During the previous year, the ICC (International Chamber of Commerce) had launched the 16 principles of the Business Charter for Sustainable Development, which guides companies in their efforts to manage the environment. ABB has subscribed to the ICC's 16 principles, along with approximately 2500 companies around the world.

ABB's international environmental organization constitutes a framework in which progress on the environmental development of production has been achieved by means of regular environmental audits.

In recent years, environmental management programs in accordance with international standard ISO 14001 have been introduced.

LCA - comparative development

For products with a long service life, such as generators and turbines, the impact on the environment is greater during the usage phase than during their manufacture. The fact that attention has shifted to the products themselves means that increased interest is being shown in the measurement of their environmental performance.

LCA work began at ABB in 1992, and in 1995 the first LCA tool was introduced. By 1998, this had made way for the second generation – the 'EcoLab Tool' – which is used today in several ABB business areas.

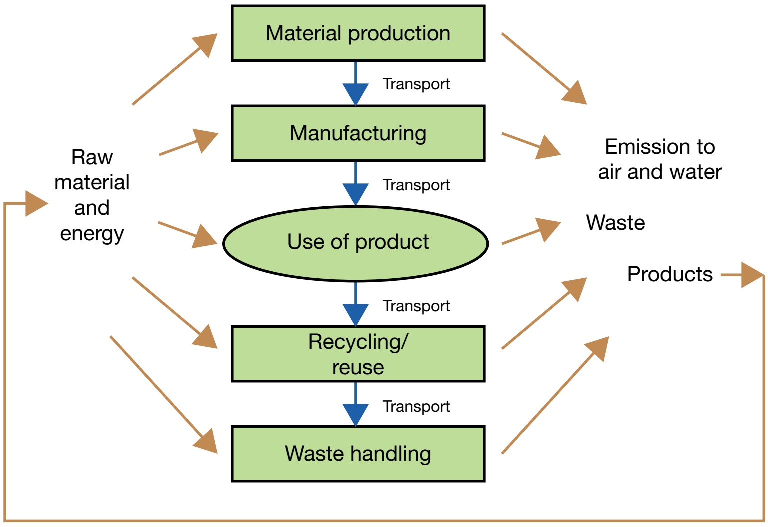
During 1999, the products and their environmental impact came under even more scrutiny through 'Goal 2000', which decreed that environmental objectives and programs for all core products be established during the year 2000.

LCA describes the environmental impact from an overall perspective 1 , and was first used in the USA at the end of the 1980s. It is a comparative method, where a product is compared to two or several technically equal products.

A product's life cycle begins with the mining or extraction of the raw materials/resources. This is followed by the processing phase, such as the production of steel from ore. The processed materials are then used to manufacture products and systems. The next phase is utilization by the customers.

When the product has reached the end of its useful life, components are reused and the material is recycled. Some of the material may land up in waste deposit sites. Transportation between the various steps in the life cycle also makes a contribution to the environmental impact.

1 The environmental impact of a product's various life cycle phases

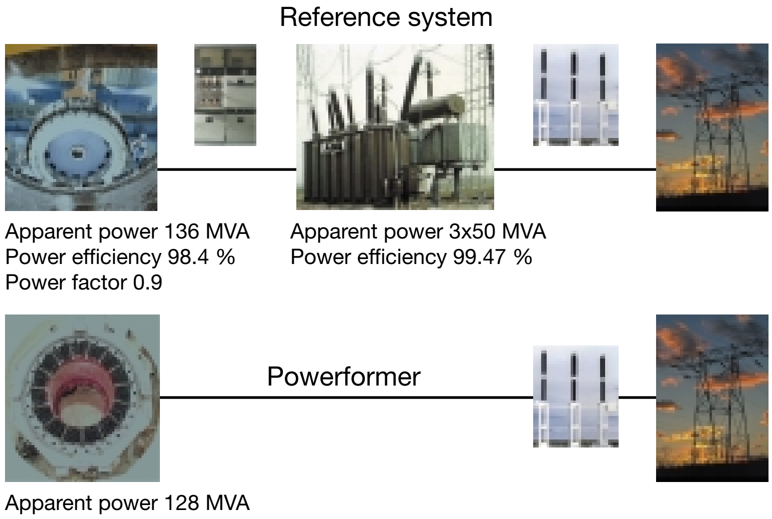


Rules for LCA

When developing new products, respect for the environment should be given the same priority as technology and economy. The materials that are used should not have an adverse effect on either the natural or the working environment. Rare materials should be used restrictively.

Clean manufacturing processes should be aimed for. Products must use energy economically and require minimal maintenance in service. Transportation must be optimized.

Good subcontractors must be appointed, since accountability does not stop at the factory gate. It must be possible to disassemble the products after use and the materials must be recyclable or capable of being used to produce energy (heat recovery).



2 Plant areas considered in LCA comparison of Powerformer™ and a system with conventional generator and step-up transformer

To meet these demands and aim at more environmentally friendly products, Life Cycle Assessment needs to be incorporated very early, ie during the development phase. The results of the assessment can also be used as basic data for marketing and environmental product declarations.

LCA is an important instrument in ABB's environmental program and is standardized in accordance with ISO 14040-43.

First, definitions

When studying, eg, a system, the first step is to formulate the objectives and scope, describing for example the system limits and functional unit.

The results depend on the system limits. Should a product, such as a generator, be studied individually or should it be assessed in its proper context, together with the other equipment in a power plant?

The function unit should reflect the function of a system. The function of a power plant is to generate electricity. 1 MWh of electricity produced can fittingly be chosen as a functional unit, to which all values in the assessment are then related. The results of the analysis are interpreted in order to formulate conclusions and recommendations for improvements.

A tool to fit the job

Where large quantities of data are involved, as in LCA, data processing tools are essential. ABB uses the EcoLab LCA Tool to simplify numerical calculations, communications and data storage. The EcoLab database has been adapted to suit ABB's needs, and currently contains just over 600 materials and processes. It is compatible with a general database for life cycle studies at CPM, a competence center for environmental assessment of product and material systems at Chalmers University of Technology in Gothenburg, Sweden.

LCA applied to Powerformer™

In the following case study, LCA was used to compare the environmental impact of Powerformer, ABB's new high-voltage generator, with that of a system featuring a conventional generator and step-up transformer.

While the voltage in a transmission network can be 800 kV or more, a conventional generator has an upper limit of only 3-30 kV. A step-up transformer is therefore needed to connect the generator to a transmission network.

Powerformer, on the other hand, can be connected directly to a transmission network without a transformer. The use of circular instead of rectangular conductors has made it possible to increase the voltage output of the generator to the grid voltage level. A plant using Powerformer will accordingly be simpler and more compact, and does not require as much maintenance as a conventional plant with an oil-filled transformer.

In the LCA study, the system limits extend from the generator to the HV substation 2 . The system with Powerformer covers the high-voltage generator and the cables as far as the HV substation, while the conventional system covers the generator, transformer, surge arrester, voltage and current transformers plus busbar. The transmission network is rated at 130 kV in each case.

The system using Powerformer provides

3 A product's impact on the environment – from emissions through the direct consequences to how people perceive they are affected

the same active and reactive power to the network as the system with conventional generator and transformer. The functional unit that was chosen is 1 MWh of electricity from the system. All inflow and outflow is related to 1 MWh of electricity [1].

The manufacturing phase inventory includes material from the systems and processes for production of the generator, transformer and cables. Data has been collected from ABB Alstom Power, ABB Transformers and ABB High Voltage Cables.

During the utilization phase, environmental impact is chiefly indirect and caused by electrical losses. The assumption has been made that the electrical losses are replaced by the Swedish electricity mix (52% hydropower, 44% nuclear power and 4% fossil fuels). The operating time is set at 30 years x 4000 hours per year.

At the end of the system life it is assumed that all metallic materials will be recycled, polymer materials will be incinerated and the heat recovered, and the remainder will be deposited as waste.

The underlying data for material and energy production is from ABB's database. Data on steel, for example, ranges from mining to the finished steel product, eg steel profile or steel sheet. Data on energy comprises the extraction of fuel (uranium, coal, etc), building of power stations, running of the plant, transportation, etc.

Breakdown into three stages

The impact of a product on the environment can be described on three levels. The first is objective – quantification of the emissions and use of material and energy resources during the life cycle of a product. At the next level the potential environmental impact is estimated. Finally, at the third level, a subjective assessment is made of the potential environmental impact.

This can be illustrated by looking at an industrial plant or facility for producing electrical power. The facility emits pollutants into the atmosphere 3 . The ground and water are affected by the emissions in a reasonably predictable way. But how does the local population rate the environment if it becomes so polluted that a number of plants and animals disappear?

At level 1 an inventory of the inflows and outflows is drawn up. The inflows constitute material and energy resources that are needed in the system, and the outflows the emissions into the atmosphere and water, as well as waste to be dumped. It can be gauged from this inventory how many kilograms of sulfur dioxide, nitric oxides and carbon dioxide are being emitted, or how much steel and copper has been used in the products or system.

The potential impact on the environment is estimated at level 2. The fall-out of sulfur and nitric oxides over lakes contributes to their acidification. Carbon dioxide emissions contribute to the greenhouse effect.

At level 3, the various products' impact on the environment is summarized: acidification, greenhouse effect, etc. The contributions are weighted and summed to form one or more totals. The assessment methods which are used are designed to represent and describe how the community is expected to rate the various contributions.

Resources and emissions

The resource consumption and emissions of the two studied systems are outlined. Steel and copper comprise the bulk of the material used, but there are other materials to consider as well. Materials worth noting in this context are XLPE (cross-linked polyethylene), fiberglass and EPDM rubber,

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[1] The electrical production was calculated for a 30-year life cycle. Electrical production = power efficiency x power factor x no of operating hours – system losses (MWh). The functional unit is the inverse of the value calculated. Both systems produce approximately the same amount of electricity per unit of time.

all of which are used in the Powerformer stator. The conventional stator, like the rotors in both cases, contains mica, resin and fiberglass. The transformer and busbars use aluminum, resin, rubber and porcelain. There are also paper (pressboard) and oil in the transformer. The surge arresters contain porcelain and aluminum, and the zinc varistors in the surge arresters contain rare metal oxides.

4 shows the quantities of steel and copper in the systems. The weights are stated as net weights per MWh of electricity produced.

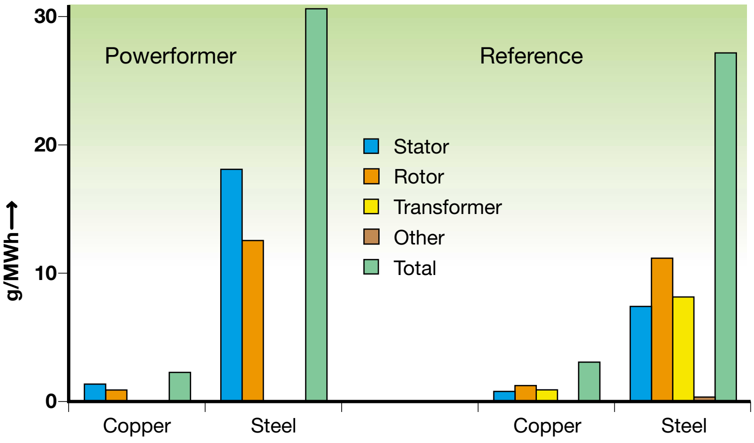
More copper is used in the conventional system than in Powerformer, chiefly because of the copper content in the transformer.

The Powerformer system has more steel, mainly because the Powerformer stator has 2.5 times more electrical sheeting than the conventional machine. However, there is considerable potential for technological advances leading to lighter and smaller machines.

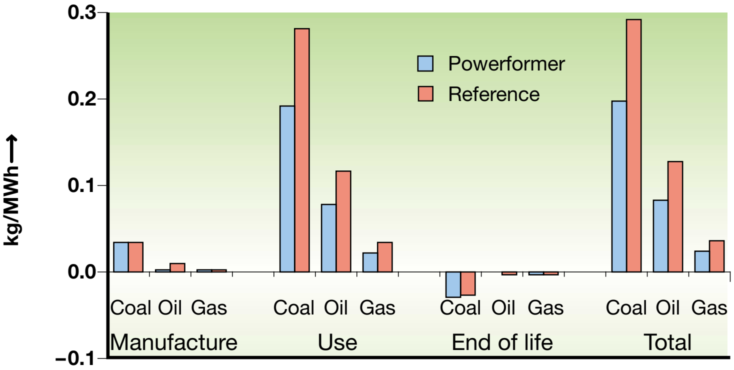
5 demonstrates how much carbon, oil and gas the respective systems consume during their life cycles. It is seen that the reference system requires more than Powerformer. In both systems, it is the utilization phase and the losses which are responsible for the greatest consumption.

Carbon dioxide, nitric oxide and sulfur dioxide emissions into the atmosphere during the various life cycle phases can be seen in 6 . The highest emissions originate from losses during the utilization phase. Emissions for the conventional system are higher than for Powerformer.

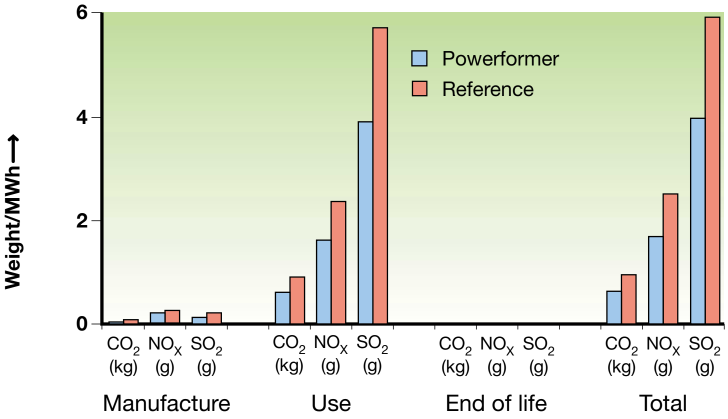
The assumption, as before, is that electricity losses are replaced by the Swedish electricity mix. If the losses are replaced by electricity from a coal-fired power plant, it will have a greater impact



4 Material consumption: net weight of copper and steel in Powerformer and the reference system



5 Consumption of coal, oil and gas with Powerformer and the reference system during their respective life cycles



6 Emissions into the atmosphere during the various life cycle phases. Losses are replaced by the Swedish electricity mix.

Note that the carbon dioxide emissions are given in kilograms per MWh of electricity, other emissions in grams per MWh of electricity.

on the environment due to the carbon dioxide and other gases which are released into the atmosphere 7 .

Carbon dioxide and nitric oxide emissions increase by just over 20 times, and sulfur dioxide emissions will be approximately 15 times greater if the electricity originates from European hard coal instead of the Swedish electricity mix with its small proportion of fossil fuels.

Estimated impact on the environment

Two good examples of how resource extraction and emissions impact the environment are acidification and the greenhouse effect (global warming):

Acidification: Sulfur dioxide and nitric oxide emissions into the atmosphere gradually 'return' to the earth's surface via rain or snow. Their high acid content (ie, low pH value) causes the soil to be depleted of nutrients, which stunts timber growth. Soil acidification leads to lakes becoming acidified, which affects fish stocks detrimentally.

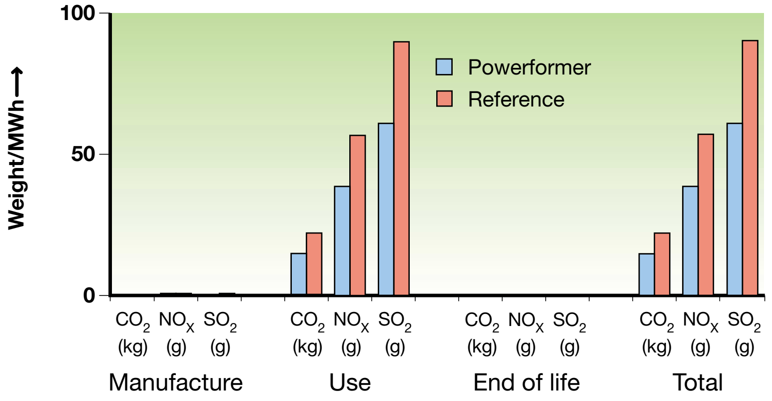
Greenhouse effect: This is caused by carbon dioxide and other gaseous emissions altering the solar radiation balance over the earth, resulting in climate changes.

How these two impacts on the environment are influenced by Powerformer and the conventional (reference) system is obviously of interest:

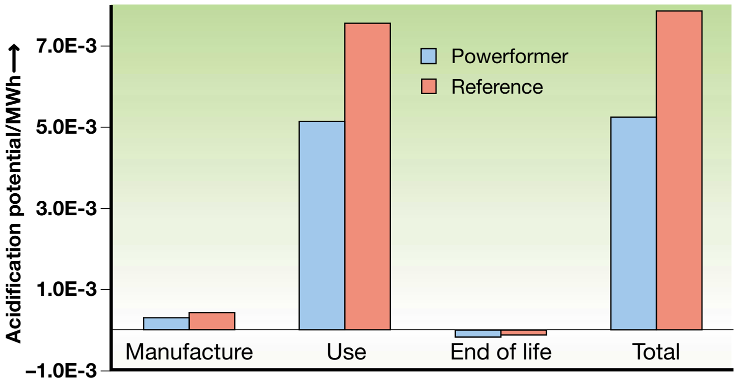
8 shows the acidification potential per life cycle phase for both systems. All of the substances that contribute to acidification are enumerated in relation to sulfur dioxide, the acidification factor of which is set at 1.

The contribution during the manufacturing phase comes mainly from the transformer in the conventional system and the stator in Powerformer 9 . As a whole, however, this contribution is very small compared with the impact resulting from utilization.

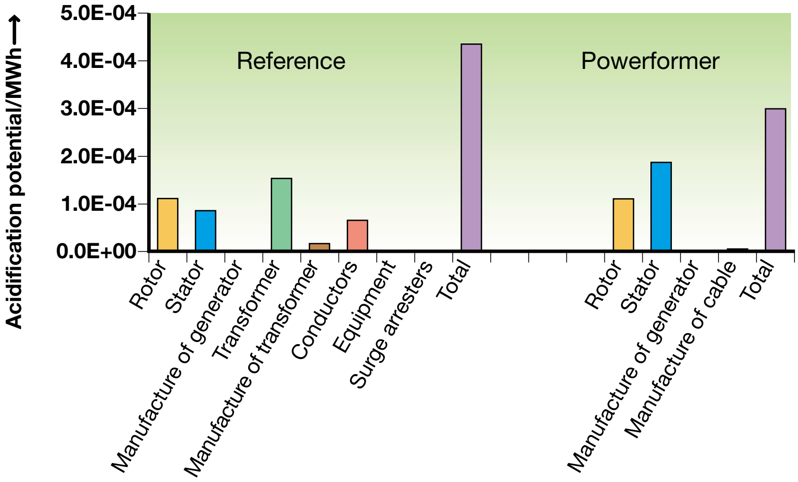
Since there are more electricity losses with the reference system, its acidification potential is greater than that of Powerformer.



7 Emissions into the atmosphere during the various life cycle phases. Losses are replaced by electricity produced from European hard coal.



8 Acidification potential for each life cycle phase



9 Acidification potential of the manufacturing phase

The global warming potential 10 is a measure of the capacity of a substance to absorb infrared radiation and contribute to an increase in global temperature. This capacity is measured in relation to carbon dioxide, the capacity of which is set at 1. Methane and nitrous oxide also contribute to the greenhouse effect.

The contribution to the global warming potential is greatest during the utilization phase. The contribution during the manufacturing phase comes chiefly from the transformer in the conventional system and from the stator in Powerformer 11 .

The manufacturing phase as a whole makes only a minor contribution to the greenhouse effect. The reference system has greater global warming potential than Powerformer because of the higher electricity losses.

Assessment

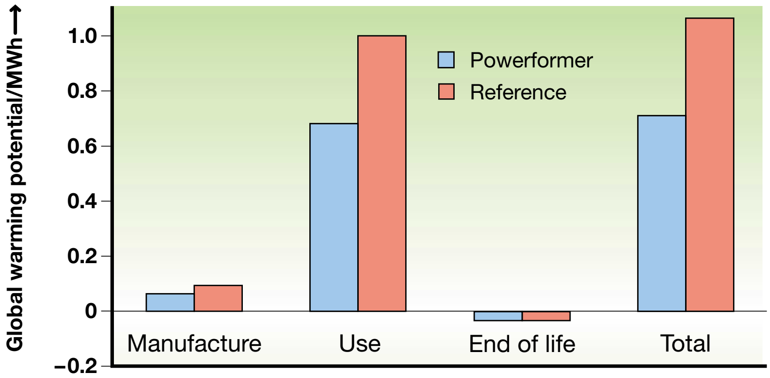
How can information such as 'the number of fish in a lake is decreasing' or the risk of large tracts of arable land being flooded be factored into an assessment of potential environmental impact? The LCA assessment methods describe from various standpoints how the community is expected to rate these effects. Two of the methods, EPS and Tellus, are presented here.

The Swedish EPS system (Environmental Priority Strategies) is based on five objects designated for protection: biological diversity (cost of protecting endangered animal and plant species), production (market prices for wood, food, etc), human health (cost of preventing deaths), resources (cost of ore extraction, etc) and aesthetic/cultural values.

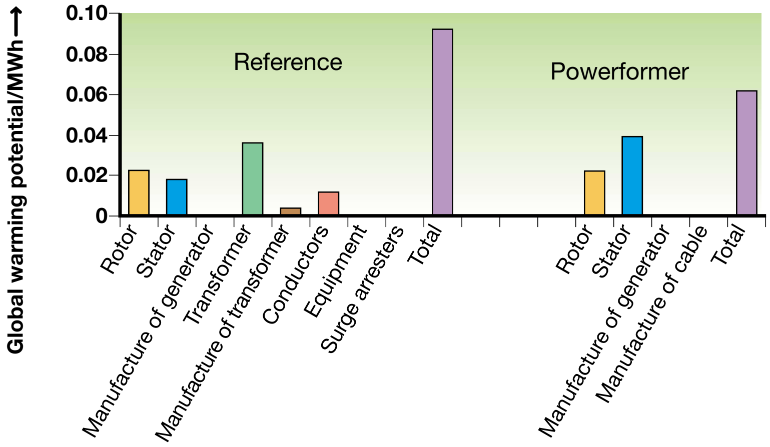
Resources, for example metals, have high ratings, while indices for effluents are often missing. Values are expressed in ELU (Environmental Load Unit).

According to EPS 12 , the conventional system is shown to have a greater impact on the environment than Powerformer.

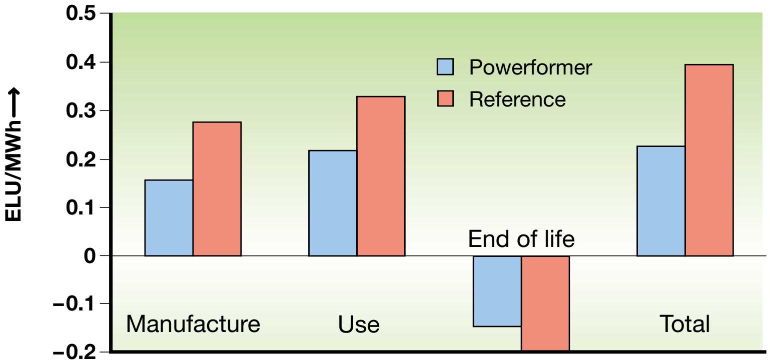
The most significant resources and emissions



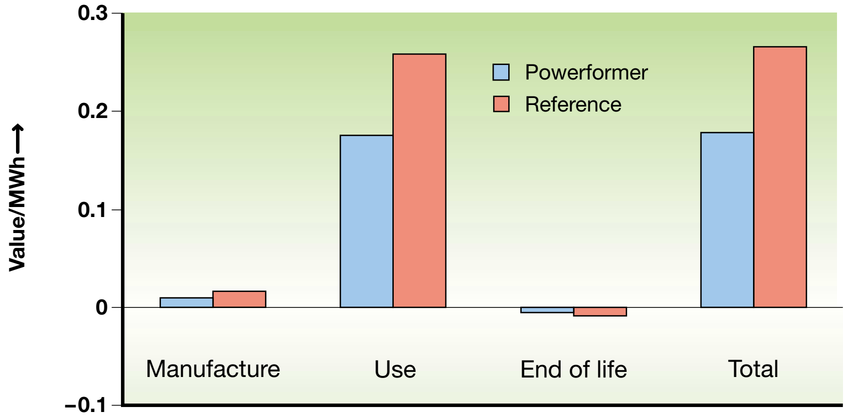
10 Global warming potential for each life cycle phase



11 Global warming potential of the manufacturing phase



12 Assessment based on the EPS system



13 Assessment made using Tellus method

are uranium, carbon dioxide emissions and oil, all of which largely originate from losses during operation. Bismuth, also a significant resource, is used in the zinc varistor.

The Tellus method from the Tellus Institute in Boston, USA, bases its assessment on the cost of avoiding the emission of toxic substances.

The assessment does not consider resources or the use of land. No differentiation is made between emissions into water and into the atmosphere.

According to Tellus 13 , the impact of the conventional system on the environment is greater than that of Powerformer.

The most significant emissions are sulfur dioxide, particles, arsenic, lead, nitric oxides and carbon dioxide, and are mainly caused by losses during operation.

Powerformer wins the eco-race

The life cycle assessment of the two different systems demonstrates that Powerformer has environmental benefits that are primarily linked to the utilization phase, where above all reduced system losses, and thereby greater power efficiency, are the factors that produce environmental gains. The simpler and more compact system solution in the new generator plant reduces the need for maintenance. Moreover, environmental hazards are reduced since there is no transformer oil.

Even the manufacturing and scrapping phases favor Powerformer, mainly due to a number of components, such as transformers, becoming superfluous. A smaller amount of material is thereby required during the manufacturing phase, and less material consequently has to be scrapped at the end of its useful life. The emission of pollutants is reduced. Another positive aspect, benefiting both the natural and the working environment, is that epoxy impregnation is avoided, as are the associated styrene emissions. The environmental impact connected with transportation is also reduced.

The usefulness of LCA methods for demonstrating the environmental life cycle superiority of Powerformer over comparable products, makes it abundantly clear that these methods can also be applied to a whole variety of other products.

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