



ABSTRACT

Transformers are critical elements of electrical networks enabling access to electricity.

Sustainability is recognized as a key global imperative, and EconiQ™ Transformers are one of the solutions from Hitachi Energy.

The four cornerstones of the EconiQ transformers framework are the reduction of carbon footprint, protection of local ecosystems, enhanced safety, and responsible use of the resources. These are built on the foundation of transparency across the value chain and product life cycle, co-creation with our customers, a toolkit of advanced technologies and solutions, and Hitachi Energy's sustainability strategy 2030.

This article explains the pathways that led us to EconiQ transformers, encompassing the why, how, and what.

EconiQ™: Transformers with a purpose

Co-creating for a sustainable energy future

Quality of life and a sustainable energy future for all

Scientists believe that impacts on the Earth's ecosystems caused by anthropogenic activities have existed since times

immemorial, and for centuries they were balanced out by the planet's capability to rejuvenate its ecosystems. However, with the advent of the industrial revolution in the 1800s, these impacts rose exponentially, triggering a loss of balance in sev-

Ambitious pathways to reach net-zero carbon emissions require concurrent transition to clean energy which would require investment in infrastructure with the deployment of clean and efficient energy technologies

eral of the Earth's self-healing processes. Today scientists are convinced that this has contributed to despoiling the planet's ecosystems, reducing the quality of life for many. With rising carbon emissions in the Earth's atmosphere, the resulting climate impacts could allegedly create an existential threat to humanity [1][2].

Ambitious pathways to reach net-zero carbon emissions require concurrent transition to clean energy. Electrification will play a key role with electricity to account for almost 50 % of total energy consumption in 2050. This will require investment in infrastructure with the deployment of clean and efficient energy technologies, such as renewables, energy storage, and new solutions like hydrogen [3]. As electricity becomes the backbone of the entire energy system, transformer technologies will contribute to the journey, supporting the sustainability efforts of the industry.

The main purpose of transformers is to enable efficient and safe generation, transmission, distribution, and consumption of

electrical energy by adapting voltage levels. With increasing complexity in grids, they are also being used for improving power quality and network management. With millions of transformers installed worldwide, there is a transformer nearby supplying you with electrical energy no matter where you are.

As with other human-related activities, transformers create environmental impacts, e.g., carbon emissions from electrical losses and mining and processing materials used in their manufacturing. Dealing with huge amounts of electricity brings upfront the relevance of energy efficiency but also some associated safety aspects that require careful management.

Understanding sustainability impacts

At Hitachi Energy, our aim is to focus on sustainability in transformers across the entire value chain, going beyond conventional financial and technical considerations to enhance benefits for all stakeholders.

When dealing with complex challenges, the first step in finding solutions is to objectively understand all associated aspects and related impacts and scientifically measure them. This gives perspective on the scale of the varied impacts and their criticality, what is known in the sustainability world as 'materiality'.

This is crucial for investing the right resources to resolve the most important issues associated with sustainability and to avoid 'green-washing.' Another important consideration is setting the 'topic boundary' or 'sphere of influence' of the manufacturer.

Materiality as defined by the [Global Reporting Initiative \[4\]](#), covers aspects that:

- Reflect the organization's significant economic, environmental and social impacts; or
- Substantively influence the assessments and decisions of stakeholders.

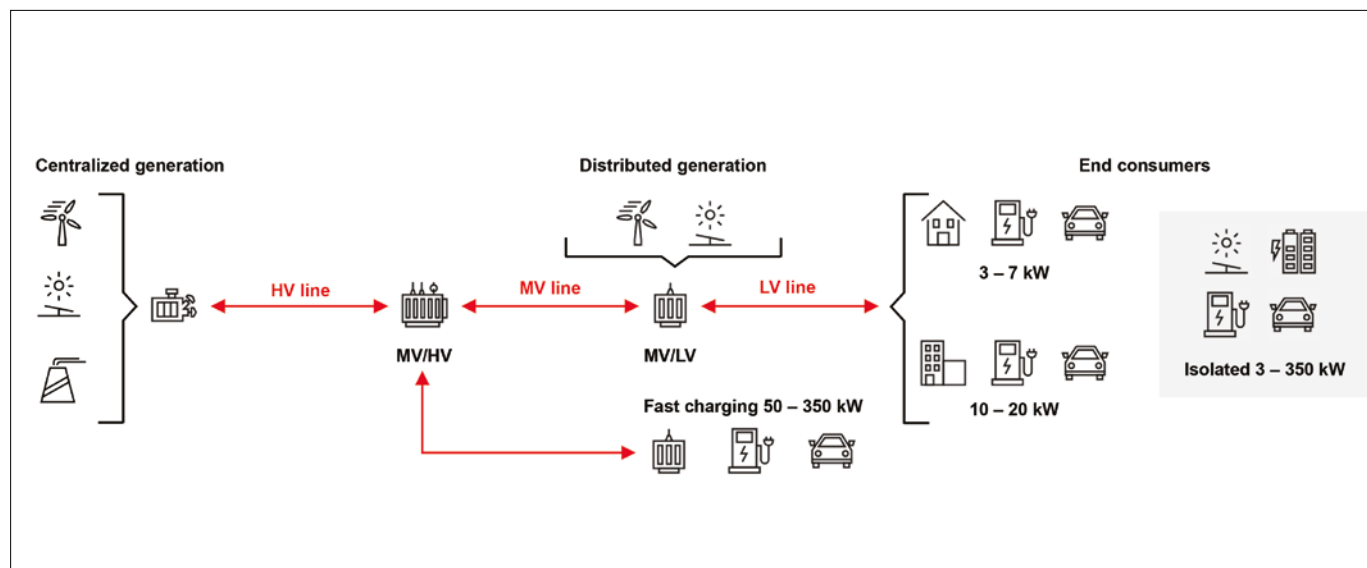


Figure 1. Electricity will be the backbone of the entire energy system, with transformers as key components

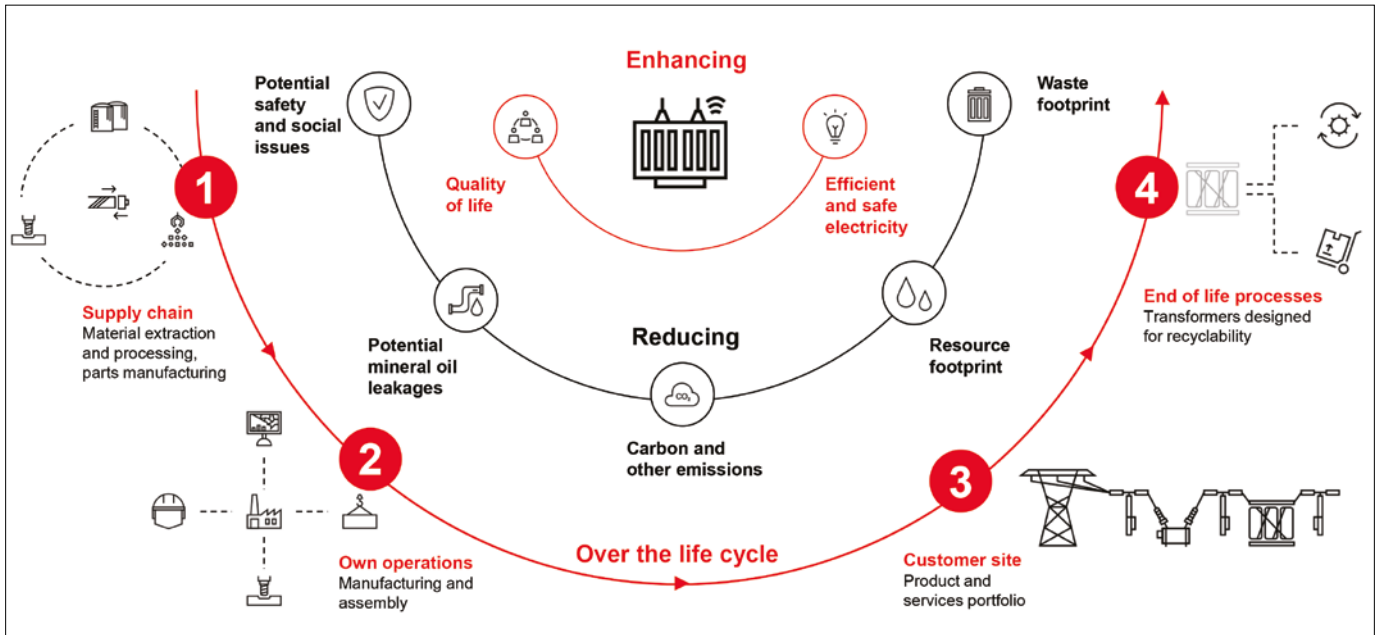


Figure 2. Hitachi Energy framework for transformers with a purpose

At Hitachi Energy, our aim is to focus on sustainability in transformers across the entire value chain, going beyond conventional financial and technical considerations to enhance benefits for all stakeholders

Sphere of influence of an organization, as defined by ISO 26000 [5]

The concept of ‘sphere of influence’ is used to delineate the **responsibility of an organization over its impacts** and it is aligned with the guidance provided by the UN Guiding Principles on Business and Human Rights.

An organization is responsible for the impacts of decisions and activities over which it has formal and/or de facto control. **In addition, an organization may in some situations have the ability to affect the behaviour of an organization with which it has a relationship. Such situations fall within the organization’s sphere of influence.**

Sustainability is a multi-dimensional field with several co-dependent variables that adds complexity and the Life Cycle Assessment (LCA) methodology based on ISO standards is today considered the most scientific and credible system for measuring and communicating its impacts, coming as close to the reality as available methodologies today allow.

What is a LCA - basic concept and process

Life Cycle Assessment (LCA) is a holistic and science-based methodology that investigates and quantifies the environmental impact of a product, service or system from cradle to grave - throughout its life cycle.

This includes evaluating energy and resource consumption as well as emissions from all life cycle stages including material production, manufacturing, use and maintenance and end-of-life.

An LCA is divided into four phases. In accordance with the current terminology of the International Organization for Standardization (ISO), the phases are called goal and scope definition, inventory analysis, impact assessment, and interpretation and can be used in many ways, depending on how the goal and scope are defined, i.e., product or service development, decision making, indicator identification and marketing as examples of areas where the information retrieved from an LCA may be useful (Fig. 3).

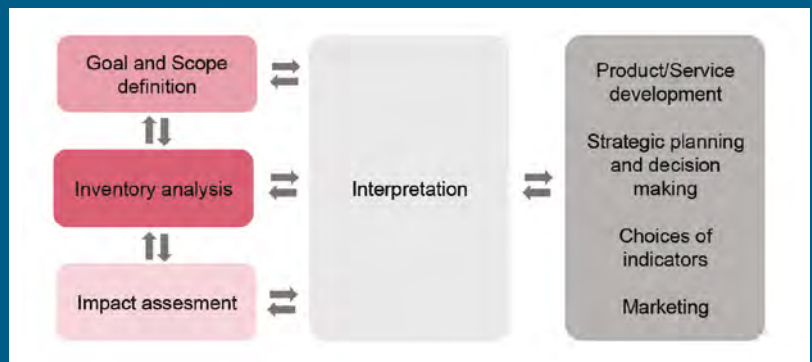


Figure 3. Life Cycle Analysis phases

LCAs follow standardized methodology (ISO 14040 14044), databases, and expertise to show, in addition to carbon footprint, other environmental hot spots, like the phase of life and materials that have the highest water footprint, toxicity, etc.

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At Hitachi Energy, we have based driving sustainability in our transformers on the foundation of providing transparency obtained from Life Cycle Assessments studies, based on which we have developed a cradle to grave LCA model for transformers (Fig. 4).

The LCA model has been built considering different environmental impact categories and involves creating an inventory of flows from and to nature for a product system. It is the process of quantifying raw material and energy requirements, atmospheric emissions, land emissions, water emissions, resource uses, and other releases over the life cycle of a product or process.

As a reference for transformers, the table on the next page gives the results of a cradle to grave LCA study of a typical 40 MVA 115 kV conducted by Hitachi Energy. It shows multi-dimensional sustainability impacts (the results are provided as a reference only based on the following assumptions: EU-28 Electricity grid mix during the complete life cycle of the transformer, manufacturing location in Italy, 35-year lifetime, 50 % loading, generic data for raw material extraction is taken from Sphera database delivered with GaBi software).

The framework of EconiQ™ Transformers

The objective of enhancing the sustainable performance of products is to minimize any adverse social and environmental impacts across their life cycle, encompassing associated activities in the business value stream.



Figure 4. Cradle to grave LCA across the whole transformers value chain



EconIQ™ Transformers provide the solution through a best-in-class framework that pushes boundaries in the sustainability performance of transformers based on material impacts and reasonable system requirements

Environmental impact categories and reference values from a LCA study of a typical 40 MVA, 115 kV transformer

Environmental impact category	Category indicator equivalent unit	35-year lifetime reference value
Abiotic Depletion (ADP elements)	kg Sb eq.	2.59E+01
Abiotic Depletion (ADP fossils)	MJ	9.05E+07
Acidification Potential	kg SO2 eq.	1.62E+04
Blue water use	kg	5.45E+08
Eutrophication Potential	kg Phosphate eq.	1.85E+03
Freshwater Aquatic Ecotoxicity Pot. (FAETP inf.)	kg DCB eq.	1.94E+04
Global warming Potential excl. biogenic carbon	tons CO2 eq.	8.02E+03
Human Toxicity Potential (HTP inf.)	kg DCB eq.	4.26E+05
Marine Aquatic Ecotoxicity Pot. (MAETP inf.)	kg DCB eq.	9.57E+08
Ozone Layer Depletion Potential	kg R11 eq.	3.98E-04
Prim. energy ren. and non ren.)	MJ	2.09E+08
Photochemical Ozone Creation Potential (POCP)	kg Ethene eq.	1.18E+03
Terrestrial Ecotoxicity Potential (TETP inf.)	kg DCB eq.	9.92E+03

The challenge is to achieve the above in a sustained way as ‘sustainable performance’ itself is a moving target based on the evolution of technology, scientific knowledge of the interactions of system flows between product systems and nature, and finally, the shifting values held by society.

‘EconIQ Transformers’ provide the solution through a best-in-class framework that pushes boundaries in the sustainability performance of transformers based on material impacts and reasonable system requirements, implying by definition the flexibility to adapt and evolve. It is based on:

- The use of science-based methodologies such as Life Cycle Analysis studies for obtaining transparency on impacts across the life cycle.

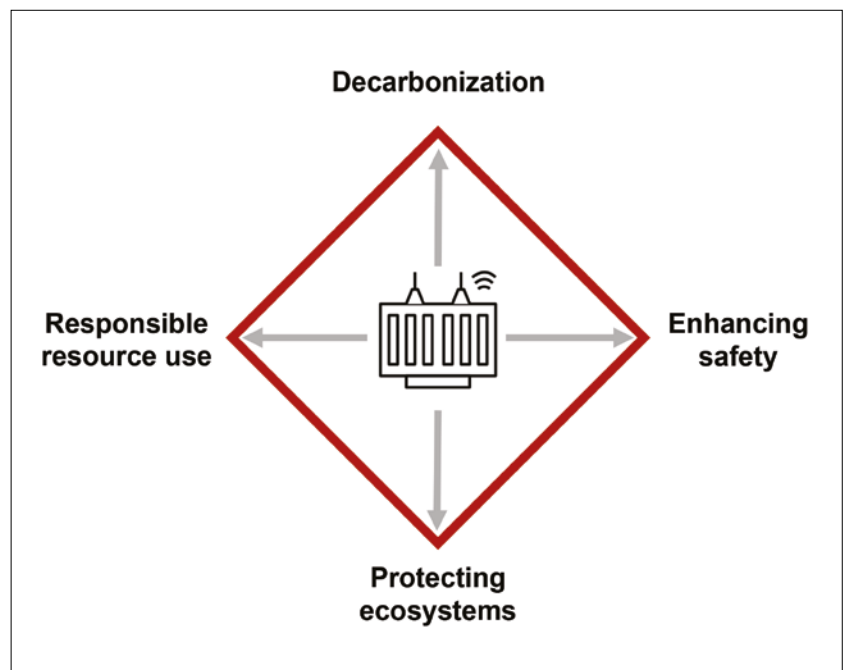


Figure 5. EconIQ™ transformers' four areas of impact

- A toolkit of best-in-class technology solutions for addressing the impacts across four main areas (Fig. 5):
 - decarbonization,
 - ecosystem protection,
 - enhanced safety,
 - responsible use of resources.
- Co-creating with our customers customized and optimized solutions to drive their sustainability journey based on the specific application, site conditions and other requirements.

Why co-creation?

Co-creation is a form of collaborative innovation defined as the process in which input from users and other stakeholders (e.g., customers, suppliers, industry experts, local communities) plays a central role in the development of the product, service, or solution, with the aim of creating maximum value for all. We also need to acknowledge that there is more than one approach to the path and varying levels of maturity in the value stream.

For example, transformers are used in different applications and site conditions. This is where co-creation plays a central role, as one size does not fit all, and we need to work together to find the optimum solution.

In its essence, sustainability is a call for action to manufacturers, suppliers, users, system operators, experts, and society in general, and any gain across the value chain will add on and contribute to the final outcome.

Material sustainability impacts in transformers and solutions to address them

EconIQ transformers provide the framework for optimizing sustainability gains in the four areas indicated be-

Transformers are used in different applications and site conditions, which means that co-creation plays a central role since one size does not fit all, and we need to work together to find the optimum solution

low, identified for driving sustainability performance in transformers based on Life Cycle Analysis (LCA) studies and our deep domain knowledge.

Decarbonization

As per the International Energy Agency (IEA), electrical losses in grids worldwide resulted in around 1 gigaton of carbon emissions in 2018. IEA also estimates that these can be reduced by over 400 million tons by improving efficient levels in the grid [6].

Even though transformers are highly efficient electrical devices with efficiencies ranging from 95 to over 99 %, there are millions of them in electrical networks around the world, providing service 24/7 with electricity passing through four to five transformers on average from generation to consumption.

The net result is that about 5 % of electricity produced worldwide is lost as heat losses in transformer operations which contribute to a major part of the total carbon emissions from the grid [7].

In addition, there are associated carbon emissions in the transformer lifecycle from other sources as well, such as from extraction and processing of materials, suppliers' operations, transformer manufacturing operations, maintenance, end of life disposal, and recycling.

However, considering today's energy mix in most locations across the world, transformer losses contribute to the most significant share of carbon emissions, and enhancing energy efficiency remains key to decarbonization, even if their effect will gradually decrease as we move towards cleaner electricity generation sources. Therefore, for the mid-to-long term carbon emissions from factors other than transformer should not be overlooked.

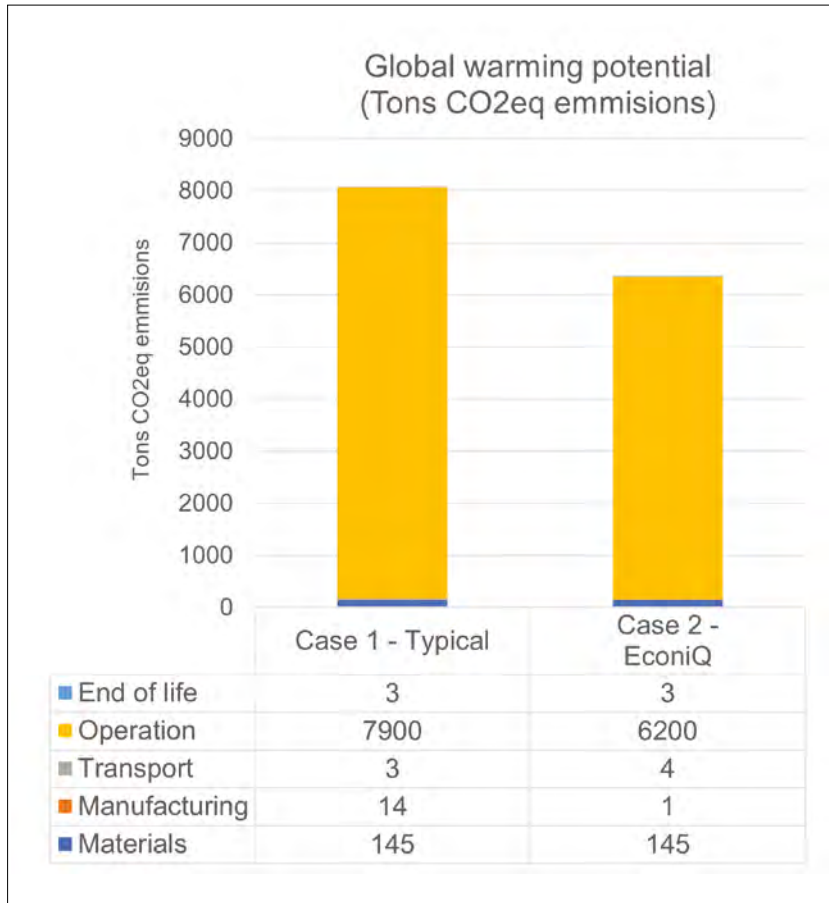
This is especially relevant as designing transformers with higher energy efficiency levels (lower losses) implies building transformers that consume more material like steel, copper (or aluminium), and insulation, and mining and processing of all of them have associated carbon emissions and other pollutants.

Considering today's energy mix across the world, transformer losses contribute to the most significant share of carbon emissions, and enhancing transformers' energy efficiency remains a key to decarbonization

Transformer data: 40 MVA, 115 ± 9 x 1.7 % / 2 kV, 50 Hz.

Case	Load losses (kW)	No-load losses (kW)	Weight (tons)	Peak efficiency index, PEI (%)	Minimum PEI, Tier 2 EUR	Insulating fluid
1 - Typical	205	14	60	99.7321 %	99.724 %	Mineral oil
2 - EconIQ	165	10	75	99.7969 %	99.724 %	Natural ester

The EconIQ optimized transformer provides a reduction of over 21 % in the total carbon emissions across the lifecycle



Graph 1: Lifetime carbon emissions of a typical 40 MVA 115 kV power transformer as compared with an EconIQ transformer

To reiterate, it is evident from the above and LCA studies that quantify carbon emissions across the life cycle that optimization needs to be done based on the transformer application and electricity mix, loading profile, and materials used, considering carbon footprint reduction measures associated not only from losses but other sources as well.

Graph 1 presents an example of lifetime carbon emissions of a typical 40 MVA 115 kV power transformer as compared

with an EconIQ transformer of the same ratings having the following features:

- Higher energy efficiency (lower losses).
- Use of natural ester fluid instead of mineral oil.
- Transformer manufacturing operations with fossil-free electricity.

The LCA considered manufacturing in Europe, 35 years operational life, 50 % loading, and EU electricity mix in operations.

Although the oil leakages from transformers are rare, to prevent ecosystems from pollution, all EconIQ transformers come with biodegradable fluids

With respect to carbon emissions associated only with materials, the four largest contributors are carbon steel, electrical steel, copper (or aluminium), and insulating fluid.

Looking at the results, the EconIQ optimized transformer provides a **reduction of over 21 % in the total carbon emissions across the lifecycle**. The major contribution comes from lower emissions during operation associated with losses but also from the use of fossil-free electricity in manufacturing and the use of natural esters:

- Manufacturing with fossil-free electricity:
If only **the manufacturing operations and materials contributions were considered, the use of fossil-free electricity during transformer manufacturing results in a reduction of approximately of 8 % of the carbon footprint.**
- Use of natural esters (or crop-based insulation fluids):
Transformers with fluids from crop-based sources, like natural esters, further contribute to reduce carbon emissions due to the biogenic capture of carbon by the plants from which ester fluids are produced (Graph 2).

Protecting local ecosystems

Mineral oil leakages from transformers in operation or from their manufacturing sites are rare, but if they happen and the spill cannot be contained, the surrounding ecosystem (terrestrial and water) will get polluted. On this basis, the use of biodegradable fluids provides a sustainable alternative to mineral oil.

Use of biodegradable fluids

All EconIQ transformers come with biodegradable fluids, and as shown in Fig. 6, evidence from LCAs indicates improvements in the following environmental impacts to local ecosystems as compared to transformers that use mineral oil:

- 15 % reduction in eutrophication, and
- 15 % reduction in water toxicity over the transformer lifecycle in case of no oil leakages,
- 100 % impact of both eutrophication

The use of ester or other high flash point fluids in the EconiQ transformers also helps to mitigate the risks associated with fire, contributing to enhancing the safety of people and other equipment in the substation

and water toxicity eliminated in the event of a significant leak.

The EconiQ toolkit also incorporates other technologies that could be selected to further contribute to ecosystem protection through:

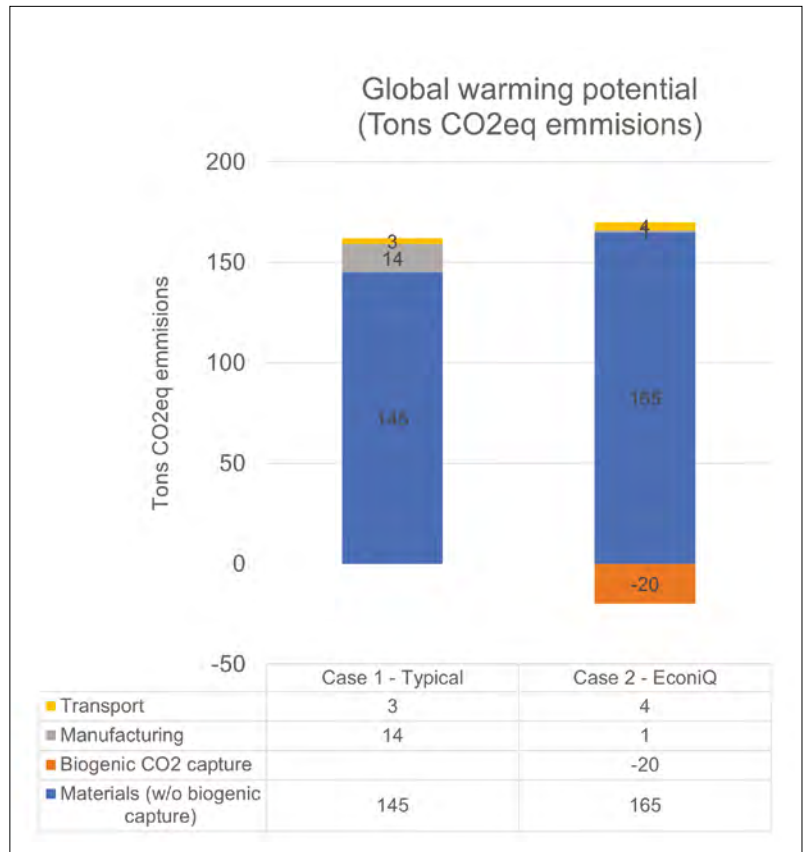
- Reduced sound levels, considering both no-load and load-related noise.
- Mitigation of risks of large oil spills by deploying the TXpand™ solution, an explosion proof tank design, already proven in over 80 customized designs and 160 units delivered by Hitachi Energy.

TXpand is a comprehensive solution with the tank prepared to expand, absorbing energy from arcing. This technology involves analysis and modelling to make the most rigid areas flexible, the weakest points stronger with rupture points to control the most unpredictable failures.

Enhanced safety

The use of ester or other high flash point fluids in the EconiQ transformers also helps to mitigate the risks associated with fire, contributing to enhancing the safety of people and other equipment in the substation, as does the deployment of the TXpand solution and dry bushings in the unlikely event of a failure.

While environmental life cycle analysis studies do not measure and quantify safety aspects and impacts, our experience of over a century with transformers has made it clear to us that though few and far between that safety-related inci-



Graph 2: Lifetime carbon emissions associated to materials, manufacturing and transport of a typical 40 MVA 115 kV power transformer as compared with an EconiQ transformer

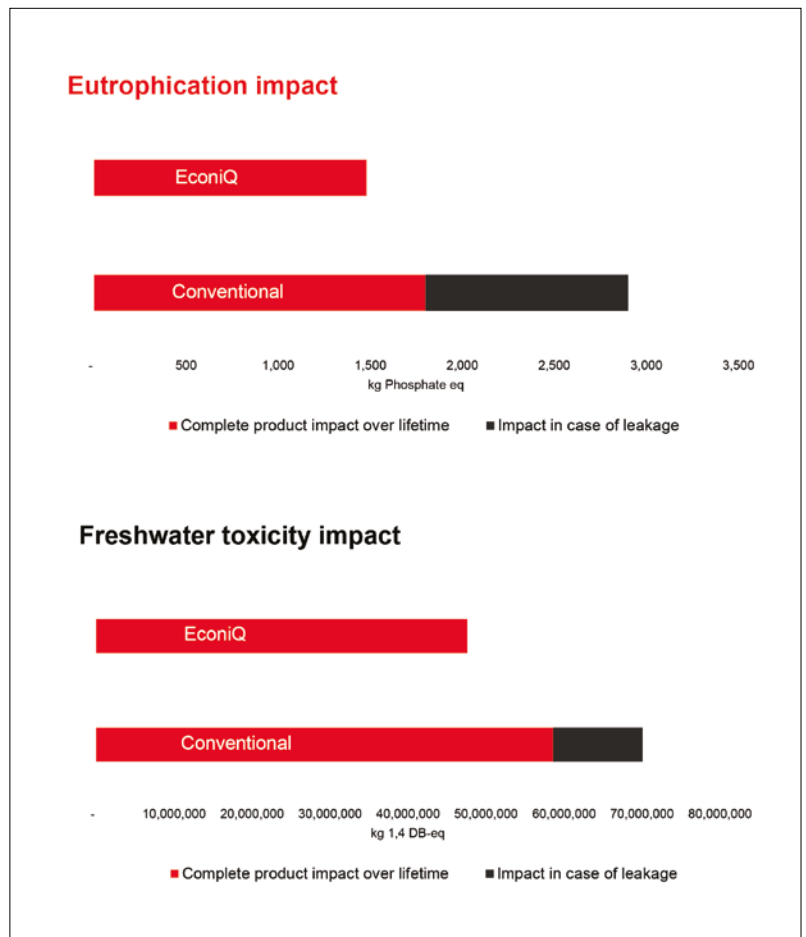


Figure 6. Eutrophication and freshwater toxicity impacts

With EconiQ, we are introducing the Extended Total Cost of ownership concept, which includes technical, financial, and sustainability considerations

dents do occur with transformers in case of special fault conditions in electrical grids. These pose safety hazards to people and property in the vicinity as widely covered in the CIGRE Brochure number 537, Guide for Transformer Fire Safety Practices. Based on this, safety is a key element of EconiQ transformers to enhance sustainability.

Responsible use of materials

With rising populations and aspirations of prosperity across the world, fueled by an even greater requirement of metals and minerals by the green energy transition, the demand for key metals is on the rise.

This poses multiple challenges such as sufficient availability of resources,

the associated environmental impacts during mining and processing materials, and recycling or disposing them at the end of life. The sustainability imperative is to use materials responsibly, which translates to reusing and recycling while also ensuring adherence to material compliance regulations.

All EconiQ transformers are delivered with a disassembly manual with recommendations for reusing, recycling, and safe disposal of any material that cannot be recycled. This is significant as transformers consume millions of tons of materials every year, most of which are reusable or recyclable.

A recent example of recycling and transformer circularity is Hitachi Energy's cooperation with Stena Recycling in

Sweden. The idea is to dispose old transformers and to reuse or recycle about 99 % of the materials, comprising 64 % material recycling, 35 % clean, low carbon incineration for energy, and the balance 1 % as scrap.

The total cost of ownership considering sustainability

Currently, the total cost of ownership (TCO) concept is widely used in the transformer industry to optimize financially the total cost of the transformer over the whole lifecycle, considering the transformer cost, the cost of losses, and other factors (such as cost of maintenance) but the sustainability benefits are in many cases not considered in the equation.

With EconiQ, we are introducing the means to extend the total cost of ownership concept to sustainability-related aspects, providing an optimized transformer solution based on a holistic framework, which includes technical, financial, and sustainability considerations.

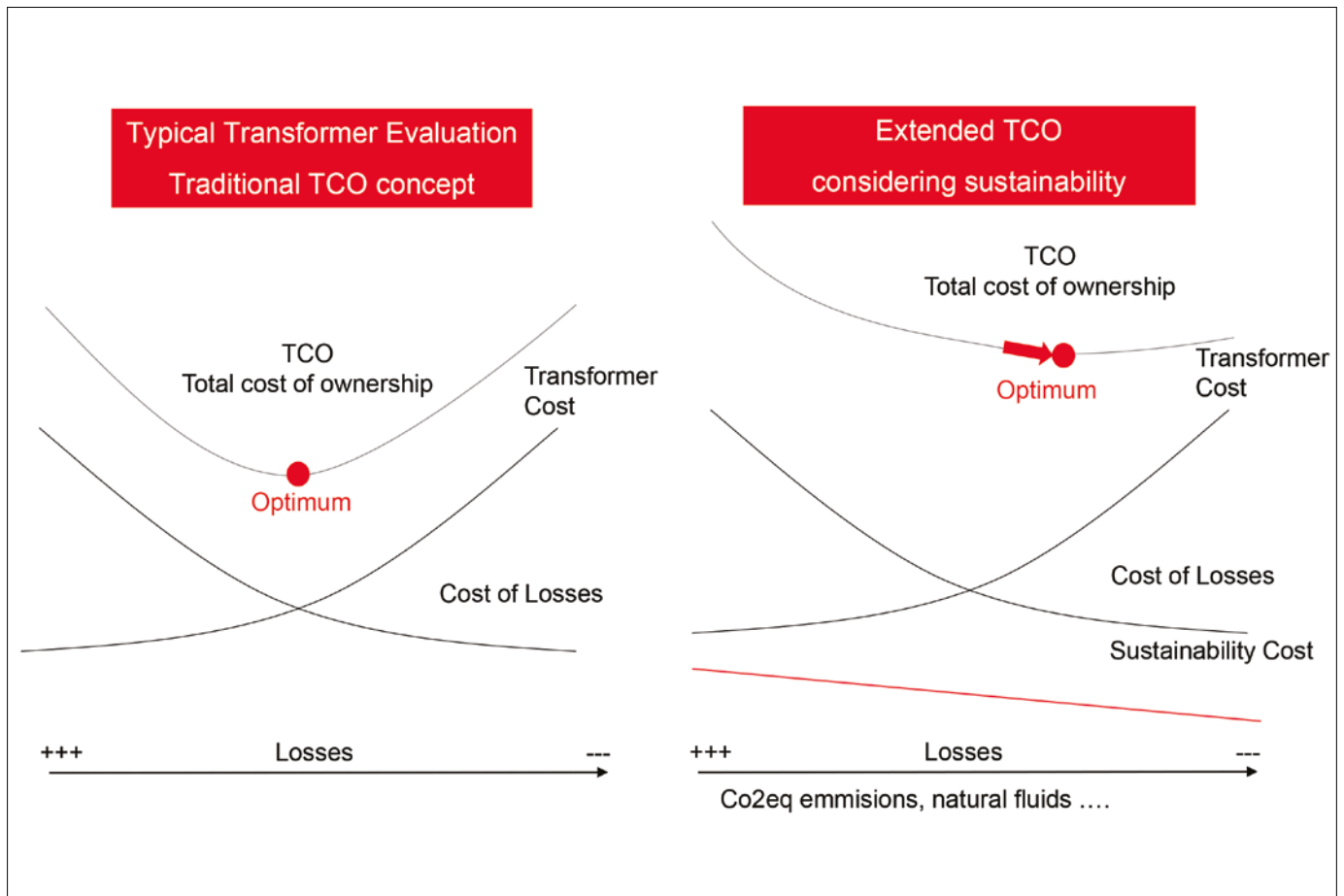


Figure 7: Extended TCO concept considering sustainability

The optimum transformer design, when considering sustainable related aspects, may differ when compared to the optimum based on a traditional TCO analysis.

In some cases, reducing losses further will lower the costs due to additional carbon footprint reduction (for example, avoiding costs on carbon credits) and those associated with risk mitigation from the use of higher flash point, biodegradable fluids as an alternative to mineral oil (for example in substation design, fire mitigation measures, insurance).

Fig. 7 provides a theoretical framework for TCO that includes sustainability costs (such as carbon and risk mitigation from mineral oil), resulting in an optimum transformer solution with lower losses.

The extended TCO concept combined with the range of design and technology solutions available within the EconiQ toolkit provide the grounds for collaboration and co-creation of

the optimum transformer adapted to the specific application and based on technical, financial, and sustainability considerations.

The consolidated definition of Liquid-Filled EconiQ Transformers

As a final recap, Fig. 8 provides a summary of the pillars of the EconiQ framework applied to liquid-filled transformers that are complemented with a scientific approach based on LCAs through collaboration and co-creation to build transformers with a purpose.

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 <p>Reduced carbon footprint over the life cycle</p>	<p>More than 20 % reduction on equivalent carbon emissions across the lifecycle.*</p>	<p>Manufactured with fossil-free electricity in our factories. Reduction in carbon emissions from TCO optimized solutions from losses or material usage, with quantified sustainability benefits.</p>
 <p>Ecosystem protection</p>	<p>15% reduction on eutrophication and water toxicity in case of no oil-spill.* 100 % reduction on eutrophication and water toxicity in case of oil-spill incident.</p>	<p>Biodegradable and higher flash-point fluids, reducing impacts of eutrophication, freshwater toxicity and minimizing fire hazards.</p>
 <p>Enhanced safety</p>	<p>Avoidance of fire risk or environmental impact of oil leakages.</p>	<p>Additional EconiQ solutions like, TXpand (explosion proof tanks), dry bushings and noise reduction technologies.</p>
 <p>Responsible use of resources</p>	<p>Full material compliance Commitment to provide support in disassembly and recyclability.</p>	<p>Following stringent regulations for our materials. Disassembly manual with transformer delivery, containing guidance for recycling and waste disposal.</p>

(*) Data is based on the LCA of the two examples presented in this article performed by Hitachi Energy.

Figure 8. Consolidated definition of Liquid Filled EconiQ Transformers