

## Supporting the development of Medium-Voltage Switchgear with Life Cycle Assessment and Circular Analysis: A Comparative Study of SF<sub>6</sub> and Synthetic Air Technologies

M. Azevedo<sup>1</sup>, J. Ortigueira<sup>1</sup>, B. Peixoto<sup>2</sup>, P. Lima<sup>2</sup>, R. Leite<sup>2</sup>, H. Monteiro<sup>1</sup>

<sup>1</sup> Low Carbon & Resources Efficiency, R&Di, Instituto de Soldadura e Qualidade, Portugal

<sup>2</sup> EFACEC, Porto, Portugal

Presenting author email: maazevedo@isq.pt

### Introduction

The ATE project supports the energy transition by promoting decarbonization and reducing greenhouse gas emissions, in line with the Roadmap for Carbon Neutrality 2050. Its objectives include improving material and energy efficiency, increasing the integration of renewable energy sources, enhancing energy efficiency, and fostering circular economy practices. Within this project, one of the study cases being analysed is the switchgear, responsible for the efficient management of medium-voltage distribution networks. Electrical insulation gases are essential for the operation of power equipment. SF<sub>6</sub> (sulphur hexafluoride) is widely used in medium-voltage switchgear due to its excellent dielectric properties and reliability. However, its global warming potential is extremely high, with the use of 1 kg of SF<sub>6</sub> being equivalent to the production of 24300 tons of CO<sub>2</sub>. Consequently, recent regulations, particularly Regulation (EU) 2024/573 on fluorinated greenhouse gases, are accelerating the transition towards SF<sub>6</sub>-free alternatives for electrical equipment.

### Materials and Methods

#### Goal and scope

This study aims to assess and compare the environmental impacts and circularity potential of SF<sub>6</sub> and SF<sub>6</sub>-free switchgears: Fluofix (with SF<sub>6</sub>) and evoFIX (SF<sub>6</sub>-free, using synthetic air). To quantify the environmental impacts, this study utilizes the life cycle assessment (LCA) methodology, adhering to ISO 14040, ISO 14044 and EN 15804:2012+A2:2019, to evaluate the potential environmental impacts across the life cycles of two Switchgears. Additionally, circularity indicators based on the ISO 59020 framework were selected and applied to assess aspects such as material recyclability, resource efficiency, and circular performance. Based on these findings, a subsequent LCA will be conducted to evaluate how the identified circularity aspects may influence the environmental impacts of the systems under study.

#### Life Cycle Assessment

##### Functional unit



**Functional unit:**  
Production of one switchgear unit

##### System boundaries



**System boundary:**  
Cradle-to-grave

#### Circular Analysis

##### List of indicators

Circularity Indicator	Calculation	Unit
Average reused content of an inflow (%REUI(X))	$\%REUI(X) = \left( \frac{m_{REUI(X)}}{m_{TI(X)}} \right) \times 100$	%
Average recycled content of an inflow (%RECI(X))	$\%RECI(X) = \left( \frac{m_{RECI(X)}}{m_{TI(X)}} \right) \times 100$	%
Average renewable content of an inflow (%RENI(X))	$\%RENI(X) = \left( \frac{m_{RENI(X)}}{m_{TI(X)}} \right) \times 100$	%
Average lifetime of product or material relative to industry average (R <sub>LP(X)</sub> )	$R_{LP(X)} = \left( \frac{t_{LP(X)}}{t_{ALP(X)}} \right)$	dimensionless
Per cent actual reused products and components derived from outflow (%REUO(X))	$\%REUO(X) = \left( \frac{m_{REUO(X)}}{m_{TO(X)}} \right) \times 100$	%
Per cent actual recycled material derived from outflow (%RECO(X))	$\%RECO(X) = \left( \frac{m_{RECO(X)}}{m_{TO(X)}} \right) \times 100$	%
Per cent actual recirculation of outflow (X) in the biological cycle (%RENO(X))	$\%RENO(X) = \left( \frac{m_{RENO(X)}}{m_{TO(X)}} \right) \times 100$	%
Energy intensity (I <sub>EI</sub> )	$I_{EI} = \frac{E_{TIE}}{n_{PU}}$	kWh

### Impact Assessment

- High **operational electrical losses**, mostly derived from the use phase.
- Excluding the use phase, **materials** represent a significant share of the environmental impact, mainly metals such as copper, aluminium, steel and stainless steel.
- In the new scenario, circularity indicators (CI) include an increase in equipment lifetime from 40 to 50 years, as well as the reuse of packaging and structural components, and the recycling and reintegration of the listed metals (copper – 55%, aluminium – 22%, steel and stainless steel – 31%) into the production cycle.

#### Circular Analysis

Circularity Indicator	Fluofix		evoFIX	
	Baseline	New	Baseline	New
%REUI(X)	13	43	8	33
%RECI(X)	0	25	0	26
%RENI(X)	13	-	10	-
R <sub>LP(X)</sub>	1	1.25	1	1.25
%REUO(X)	0	43	0	33
%RECO(X)	57	-	59	-
%RENO(X)	0	-	0	-
I <sub>EI</sub>	19	-	9	-

#### LCA comparison



### Conclusions

The results indicate that evoFIX presents higher environmental impacts than Fluofix, mainly due to higher material requirements, higher operational electrical losses during use phase, and the fact that it is a new product, suggesting potential for optimisation. Circularity indicators highlighted opportunities to improve eco-design and resource circularity in both systems. The integration of these indicators and the life cycle reassessment show production-stage improvements for both products. The associated impacts could be reduced through a higher share of renewable electricity, particularly during the use phase. Moreover, considering the environmental concerns associated with SF<sub>6</sub>, its substitution represents a relevant opportunity, and evoFIX may constitute a promising alternative mainly if the identified improvement aspects are addressed.