3.1.3 Typical environmental results of C4-FN technology compared to SF_6 technology

Several LCAs have been published and focus on the comparison of C4-FN products against their SF_6 equivalent. C4-FN mixtures usually achieve 59 % to 92 % reduction of the total carbon footprint of high-voltage equipment compared to state-of-the-art SF_6 products, which is a significant improvement for the environment.

These studies were mostly made by manufacturers. Without a complete PCR (see section 3.1.1), they cannot be compared between OEMs as the estimations maybe have different scopes or hypotheses. Similarly, comparisons to other technologies like vacuum interrupters with air insulation is removed from the results, when possible, as the results can be biased by the difference of quality dataset (extrapolated values).

High-voltage equipment with C4-FN mixture is compact and light, allowing a low-carbon footprint associated to its manufacturing (emissions at the time of project executions). The low-GWP in comparison to SF_6 avoids important CO_2-equivalent emissions during the use phase and maintenances, especially considering the very low permeation rate of C4-FN through the sealing material (see 2.7.2). This maintains a relatively low carbon footprint of the use-phase, dominated by Joule losses of the main and secondary circuits, including instrument transformers and anti-condensation heaters. This footprint can be optimized and will reduce with the improving energy mix of the grid.

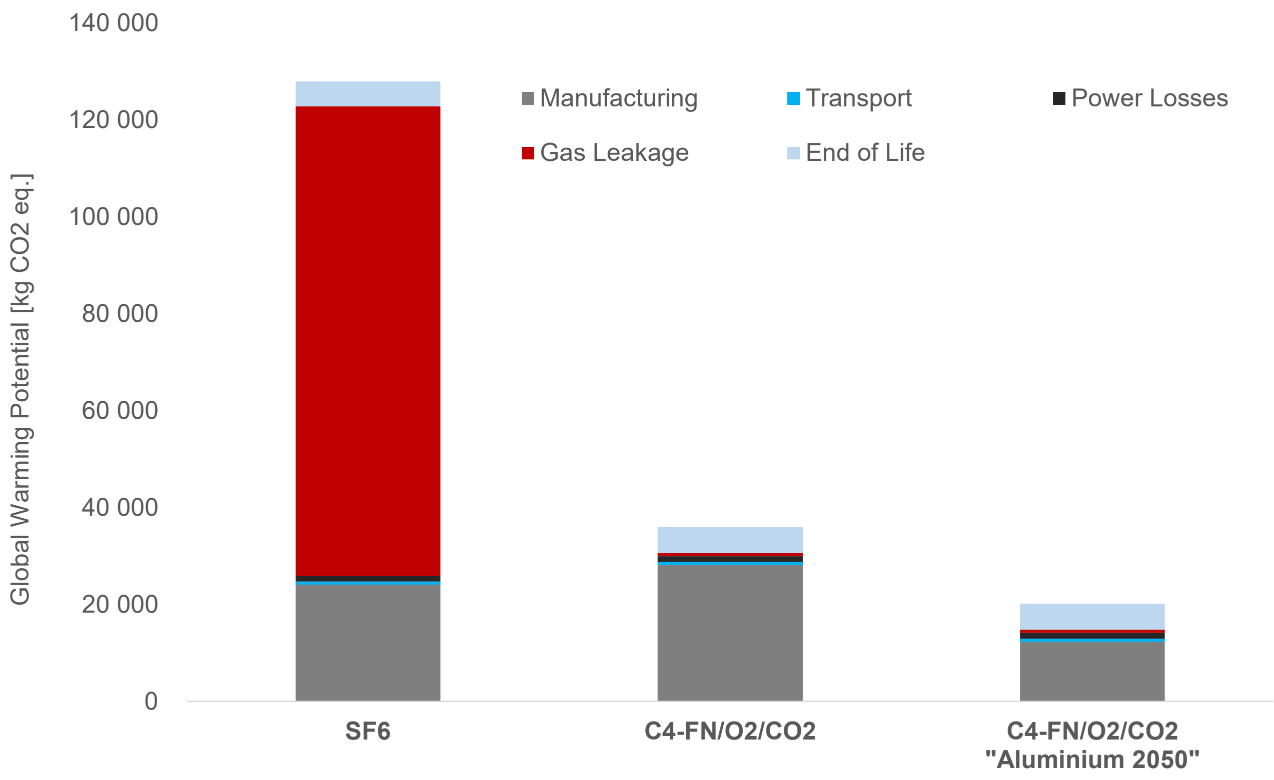
Some LCA results are presented below and grouped by category of product, as each one has its own inherent differences that change how the replacement of SF_6 impacts its CO_2-equivalent.

Dead-tank CB 72.5kV

An LCA was done to compare environmental performances of a dead-tank circuit-breaker at 72.5kV level using SF_6 and alternatives [69]. It appears that the carbon footprint was decreased by 59 % going from SF_6 to C4-FN mixture which means about 80 teq_{CO2} saved per product. The paper also highlighted that to use a lower mass of material helps to reduce CO_2-equivalent emissions at the manufacturing phase.

GIS 145 kV

A third party verified LCA was performed according to ISO 14040/14044 for a 145 kV GIS [70], [71]. A SF_6 GIS was compared to a C4-FN/O_2/CO_2 GIS with an identical specification comprising one double-busbar-bay including CB, CT, DES, FES, VT, cable connection, LCC and steel support. Over the whole life cycle, a 71 % reduction in carbon footprint could be achieved for the C4-FN/O_2/CO_2 solution (see Figure 36). This reduction is due to the lower carbon footprint of the gas that leaks during production and use phase. Additionally, there was a projected scenario “Aluminium 2050” included, where 100 % recycled aluminum was used for production of C4-FN/O_2/CO_2 GIS. This allowed a reduction of carbon footprint by 84 % compared to today’s SF6 equipment. Even in this optimistic future scenario the Aluminum consumption during manufacturing remains the main contributor to carbon footprint.



145 kV GIS: One double-busbar-bay including CB, CT, DES, FES, VT, cable connection, LCC and steel support.

Continuous current = 800 A, operation in a grid with renewable energy.

Left column:	SF_6 equipment, leakage rate = 0.1 %/year.
Middle column:	Equipment filled with C4-FN mixture, leakage rate = 0.2 %/year, production incl. aluminium in Europe (global carbon footprint of aluminum would be higher); 0 % recycled aluminum is used for production, 95 % is recycled at end of life.
Right column:	Equipment filled with C4-FN mixture, leakage rate = 0.2 %/year, production incl. aluminium in Europe, “aluminum 2050 scenario” (= 100 % recycled aluminum is used for production, 100 % is recycled at end of life), circular economy.

Figure 36: LCA (carbon footprint over 40 years) for a 145 kV GIS

It is also possible to assess environmental impact with a simplified tool even though it is less accurate than full certified LCA. The key benefit from simplified tool is the much lower time needed to compare some data. Especially, a quick tool can be developed to check and compare impacts from different material scenarios (mass and proportion) to make a product. Such approach was developed in [72] where a 145 kV GIS is calculated using SF_6 and C4-FN mixture.

During the manufacturing stage, the best candidate is C4-FN mixture due to the small impact of C4-FN mixture GWP compared to SF_6 GWP. C4-FN mixture uses a little bit more material than SF_6 due to pressure increase. This could result in a larger carbon footprint for manufacturing, but the SF_6 emissions during the gas manufacturing and the GIS manufacturing counterbalance it (see Figure 37).

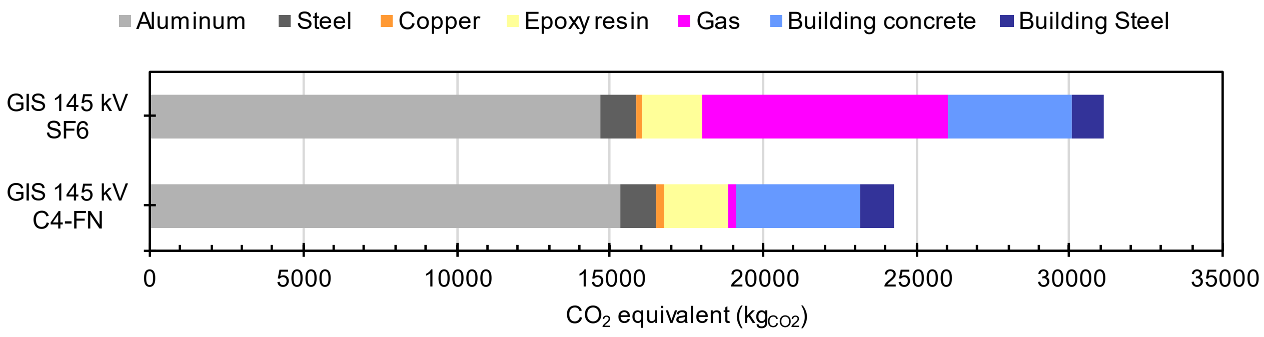


Figure 37: Simplified CO_2 footprint during manufacturing (145 kV GIS)

Then, C4-FN is much less impacting than SF_6 during the use phase. Calculations are done considering that the GWP of C4-FN mixture leaks equals the GWP of the C4-FN mixture, which is conservative as the main molecule leaking is CO_2 due to permeation effect (see section 2.7.2): C4-FN does not leak as much as CO_2 and the GWP of the leak is actually much lower than the GWP of the gas. Globally, the CO_2 footprint per year is clearly dominated by gas losses for SF_6 equipment, while for the C4-FN mixture insulated equipment electric (Joule) losses are most relevant.

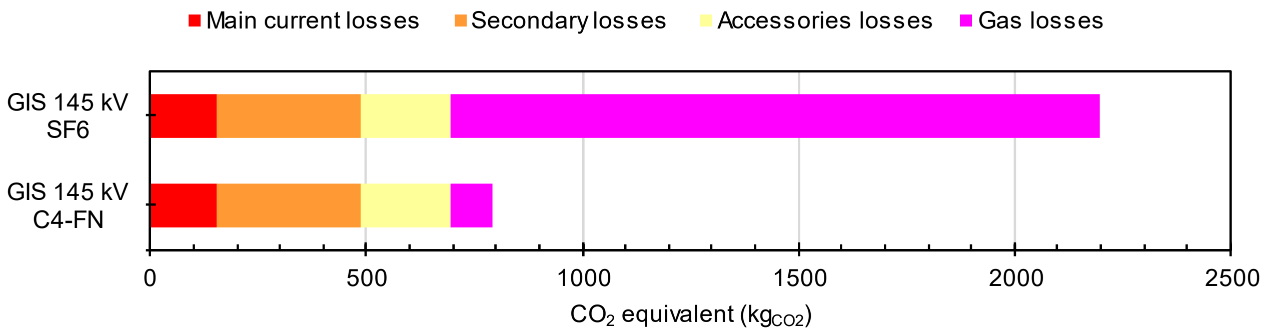


Figure 38: CO_2 footprint per year of use (145 kV GIS)

The reference result shows 58 % CO_2-equivalent reduction, but various other scenarios are presented and range from 49 % to 68 % carbon footprint reduction (Figure 39).

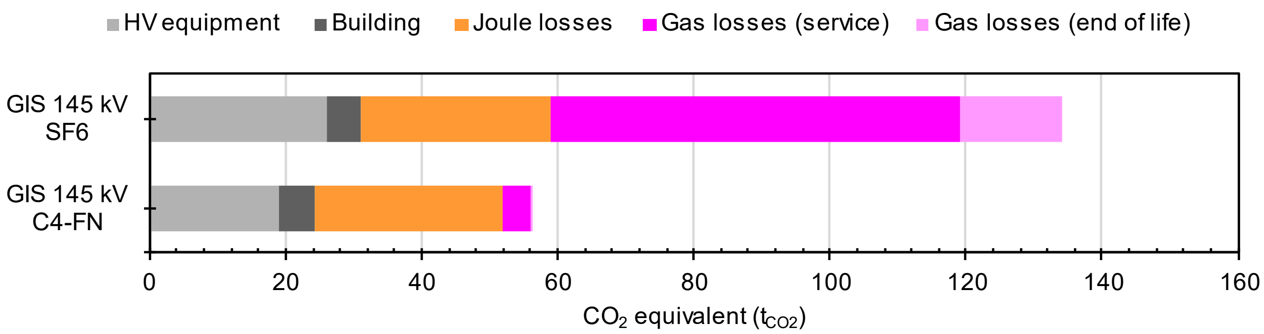


Figure 39: Simplified LCA (carbon footprint over 40 years) for a 145 kV GIS

GIS 420 kV

A new installation of a 420 kV GIS bay with 100 m GIL was assessed using SF_6 vs. C4-FN/O_2/CO_2 (see Figure 40 a) and b) respectively) [27]. For SF_6 equipment, gas losses are the dominant contribution to the equipment's carbon footprint, with more than 90 % share of CO_2-equivalent emission over the life cycle for the base scenario. Further, less important contributions are transport of components and product, resources used in assembly, testing, installation, commissioning, and maintenance and finally recycling as well as power losses due to load current.

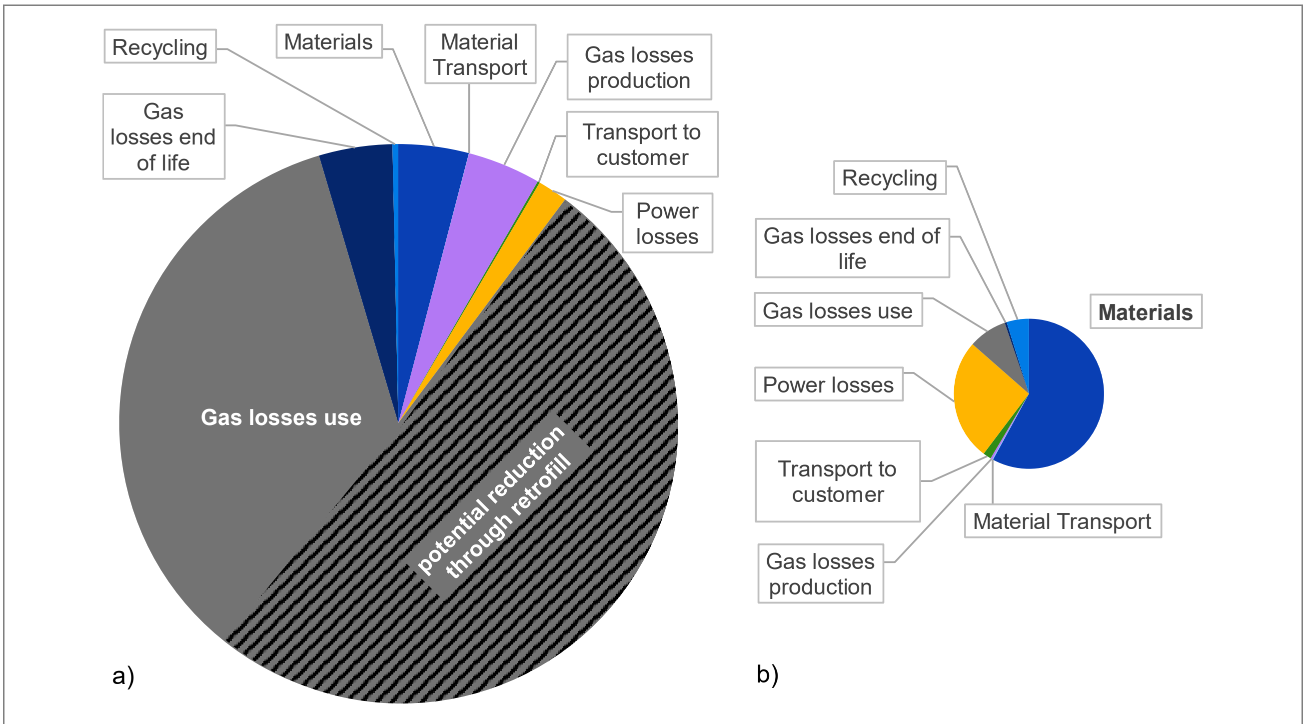
By switching to C4-FN/O_2/CO_2, the impact of gas loss on carbon footprint is virtually eliminated as CO_2-equivalent of leaked gas is reduced by 99 %. Size, material consumption and power losses of the C4-FN/O_2/CO_2 equipment are similar to the SF_6 equipment, so that the overall carbon footprint is reduced by more than 90 %. In the study [27], it is also demonstrated, that the relative numbers can change e.g., if a different load current or a lower leakage rate due to better equipment maintenance is assumed. However, the significant reduction of carbon footprint by the switch to C4-FN/O_2/CO_2 equipment, persists with an overall reduction in the range from 78 % to 92 % for the assessed scenarios.

It is confirmed by another paper claiming a 96 % reduction of carbon footprint for a 420 kV GIL [73]. On top of that, there is no transfer of pollution on other indicators such as ionizing radiation or metal depletion. The mean improvement is even 14 % on all indicators other than climate change.

GIS 420 kV Retrofill

A retrofill scenario of a 420 kV GIS bay with 100 m GIL/exit was assessed. Initially the equipment is installed, filled, and commissioned completely with SF_6 [27]. For the GIL part, a retrofill is available, meaning SF6 will be swapped with C4-FN/O_2/N_2 gas mixture. The GIS bay remains with SF_6. In case the retrofill of the GIL is performed right after commissioning, around 50 % of the total carbon footprint (59 % of total gas losses) can be avoided (see Figure 40). Since retrofit is only available for the GIL part, it should be considered, that the reduction of carbon footprint is strongly dependent on the specific layout of the installation.

SF_6 installations with long GIL can have a large share of their future CO_2-equivalent emissions removed by retrofill. The point in time after installation when the retrofit is performed is also relevant. The earlier in the life cycle the retrofill is performed the larger the share of avoided CO_2 emissions.



420 kV GIS installation: GIS bay and 100 m GIL. Continuous current = 800 A.

a) Carbon footprint for equipment filled with SF_6. Leakage rate = 0.5 %/year. Also shown is a possible reduction of the CO_2-equivalent, by filling the GIL with a C4-FN/O_2/N_2 mixture.

b) Carbon footprint for equipment (GIS and GIL) filled with a C4-FN/O_2/CO_2 mixture.

Figure 40: LCA (carbon footprint over 40 years) for a 420 kV GIS installation