# Life-cycle and atmospheric impact analysis of future reusable launch vehicles

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**Abstract.** Reusable launch vehicles (RLV) may soon reduce space access costs and enable novel breakthrough space application. Whilst space presents an ideal platform for addressing global issues, it raises an "adaptation-mitigation dilemma". Launch vehicles are the only anthropogenic object emitting directly into every atmospheric layer, and reusability may introduce additional burdens. Although it may enable the recycling of major components, its potential sustainability gains with respect to expendable launch vehicles (ELV) has not been quantified.
This study performs a preliminary life cycle and atmospheric impact assessment of the different technologies for first stage reusability with same payload capabilities. Reusability showed possible early reductions in material resource depletion which was independent of propellant choice and recovery strategies. In terms of climate forcing, reusability may only be beneficial for hydrolox, ammolox, and possibly methalox technologies if soot production is kept under sustainable limits and if carbon neutral propellant production is performed. Vertical Take-off Vehicles with Horizontal landing capabilities (VTHL) performing In-Air-Capturing recoveries also showed reduced climate forcing potential. Stratospheric ozone depletion potential was estimated to increase by 18-34 % for Vertical Take-off Vertical Landing (VTVL) vehicles, and 12-16% for VTHL with respect to ELV. In addition, high sensitivity with mixture ratios, flight profiles, staging conditions and aerodynamic capabilities was identified.. Moreover, high altitude atmospheric impacts, particularly from soot emissions, appear to dominate the potential life cycle impact and uncertainty, especially for hydrocarbon fueled launch vehicles. This is further exacerbated by the commonly used but unsuitable weighting based on aviation and ground based emissions. These might affect the absolute and relative comparisons substantially and therefore, results must be taken with caution. Future studies should employ state of art atmospheric modeling and adequate approaches to weight the various life cycle phases, enabling design for mitigation while avoiding burden shifts.

**Keywords:** Reusable launch vehicles · Life Cycle Assessment · Environmental Impact