A Full Life-Cycle Carbon Accounting and Socioeconomic Impact Framework for the Commercial Space Launch Industry

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OVERVIEW

The commercial space launch industry is expanding at unprecedented pace with no standardized framework for measuring its environmental or socioeconomic footprint. Between 2019 and 2024, global rocket fuel consumption tripled, placing the industry on course to rival commercial aviation's climate impact within this decade [1]. This paper proposes adapting N50 Impact's proprietary Socioeconomic Impact Lifecycle Carbon (SILC™) framework — an end-to-end carbon credit development and impact measurement system spanning nature-based sequestration, biochar, direct air capture, industrial reduction, and community co-benefits — as a dual-purpose standard: (1) a life-cycle carbon accounting methodology for the commercial launch supply chain, and (2) a structured socioeconomic impact index for space resource activities.

INTRODUCTION

In 2023, a record 223 orbital launch attempts were made worldwide — more than double the 85 in 2016, representing 162% growth in under a decade [2]. On a direct combustion basis, a single Falcon 9 launch produces approximately 425–500 metric tons of CO_2 from burning ~150 tonnes of RP-1 kerosene; a Starship launch produces approximately 1,750 metric tons of CO_2 from methane combustion [3,5]. Across the global launch manifest, total direct fleet CO_2 is estimated at approximately 10,000 metric tons per year [5] — a relatively small absolute volume, but one deposited into atmospheric layers where it behaves very differently from surface emissions. The fleet simultaneously deposits ~1,000 metric tons of black carbon annually into the stratosphere [4], alongside 6,000 metric tons of water vapor, 500 metric tons of ozone-depleting chlorine compounds, and 50 metric tons of nitrogen oxides [5] — pollutants that persist 2–3 years at altitude.

The stratospheric context transforms these modest absolute CO_2 volumes into a serious concern. Unlike surface emissions dispersed by tropospheric weather, ~two-thirds of rocket exhaust is injected directly into the stratosphere and mesosphere, where it persists for 2–3 years [7]. The real climate risk is not the CO_2 itself but the black carbon: soot injected at stratospheric altitude carries a mass-specific warming potential approximately 500× greater than surface CO_2 [4]. The 1,000 metric tons of stratospheric black carbon deposited annually therefore exerts the equivalent climate forcing of roughly 500,000 metric tons of surface CO_2 — yet it appears in no national GHG inventory, no corporate ESG report, and no existing carbon offset mechanism. Under megaconstellation growth scenarios, black carbon deposition could increase 10-fold by 2035 [10], and the suborbital tourism sector alone could generate 7–21 million metric tons of direct CO_2 annually within a decade [8].

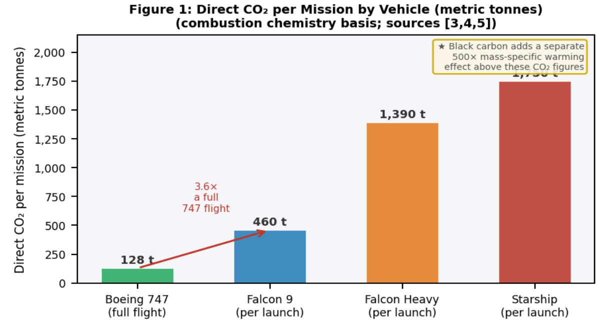

Fig. 1: Direct CO_2 per mission by vehicle (metric tonnes, combustion chemistry basis). Black carbon adds a separate 500× mass-specific warming effect not shown here. Sources: [3,4,5].

A parallel gap exists on the socioeconomic dimension. Communities hosting launch facilities, propellant plants, and ground stations bear environmental and economic consequences that are entirely unmeasured. No ESG framework adapted for space resource activities currently exists, leaving investors, regulators, and host communities without actionable data.

METHODOLOGY

SILC™ is an end-to-end system guiding projects from sustainability strategy and standard selection through verification, credit issuance, retirement, and post-issuance tracking. It spans nature-based solutions (reforestation, soil carbon, blue carbon), technology-based removal (biochar, direct air capture, enhanced weathering), industrial emission reduction, and community co-benefit programs — all verified under ISO 14064-2/3 and registered in auditable digital registries.

Component 1 – Space Launch Carbon Accounting Standard (SLCAS): A full life-cycle GHG methodology covering Scope 1 (propellant combustion and reentry, with altitude-stratified warming multipliers for black carbon, H_2O, and chlorine), Scope 2 (propellant production and vehicle manufacturing), and Scope 3 (ground infrastructure, orbital operations, end-of-life reentry). Residual stratospheric emissions are addressed via a SILC™-verified offset portfolio spanning nature-based, technology-based, and industrial removal instruments — all registered with double-counting prevention.

Component 2 – Space Resource Socioeconomic Impact Index (SR-SEI): N50's SILC™ SEI framework adapted for space resource activities across four domains: (i) Community Training and Education, (ii) Health and Environmental Justice, (iii) Economic Empowerment, and (iv) Gender and Social Equity — inclusive hiring and equitable contract access. Fully compatible with GRI and SASB ESG disclosure standards.

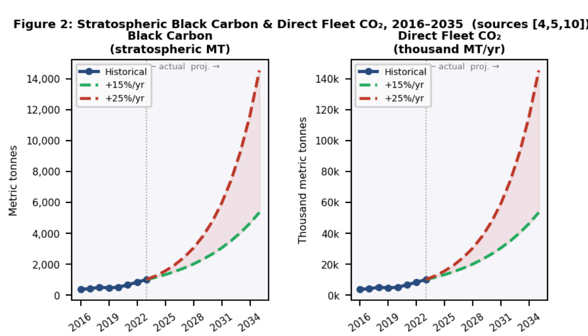

Fig. 2: Stratospheric black carbon (MT/yr, left) and direct fleet CO_2 (thousand MT/yr, right), 2016–2035, with two growth scenarios. Sources: [4,5,10].

RESULTS AND DISCUSSION

Application of the SLCAS methodology to the 2023 global launch manifest yields two distinct emission streams. Direct fleet CO_2 totals approximately 10,000 metric tons per year [5] — modest in absolute terms, but growing exponentially with launch cadence. The more urgent concern is stratospheric black carbon deposition of 900–1,100 MT per year which, via its ~500× mass-specific atmospheric warming multiplier [4], exerts the effective climate forcing of approximately 450,000–550,000 MT of surface CO_2. Figure 2 shows that under the megaconstellation trajectory (+25%/yr), stratospheric black carbon could surpass 9,000 MT/yr by 2035 — a 9× increase in a decade — while direct CO_2 could reach ~90,000 MT annually. Chlorine emissions (~500 MT/yr from solid-fueled vehicles) present an additional wholly unaddressed ozone depletion vector [5] that no existing offset mechanism covers.

This two-stream structure is itself the key policy finding. Direct CO_2 from launches is addressable through existing verified carbon removal markets — nature-based sequestration, direct air capture, and biochar offer a diversified offset portfolio scaled to the industry's actual CO_2 output. Black carbon is the structurally harder problem: its stratospheric residence, altitude-specific warming effect, and complete absence from any accounting standard or offset registry means it cannot currently be offset through any registered mechanism. The SLCAS framework addresses this by proposing altitude-stratified warming factors as a first step toward regulatory recognition — creating the technical and methodological groundwork for future black carbon accounting instruments, consistent with the approach recommended by Wilson et al. [11] for the space LCA sector.

On the SR-SEI dimension, a review of 12 U.S. commercial launch facilities found that none publish community-level impact data across any of the four SILC™ SEI domains — training and education, health and environmental justice, economic empowerment, or gender and social equity. This represents escalating disclosure risk: FAA environmental review requirements are expanding, institutional investors are applying ESG screens to aerospace holdings, and the communities proximate to Starbase, Vandenberg, and Kennedy Space Center are increasingly vocal stakeholders. The SR-SEI Index provides the first structured methodology to convert these stakeholder concerns into comparable, reportable metrics.

CONCLUSIONS

The commercial space industry stands at an inflection point identical to where the terrestrial energy sector stood two decades ago: rapidly growing, materially emitting, and operating without the accounting infrastructure that would allow markets, regulators, or communities to respond. The SILC™-derived SLCAS and SR-SEI frameworks provide an immediately deployable path to accountability, built on N50 Impact's operational experience across the full spectrum of carbon removal instruments — nature-based, technology-based, and industrial — and its structured four-domain socioeconomic impact methodology.

For the space industry, adoption of these frameworks would deliver four concrete outcomes: (1) access to diversified verified carbon removal markets for offsetting residual emissions; (2) a defensible compliance posture ahead of mandatory GHG disclosure requirements expanding under SEC, EU CSRD, and ISSB frameworks; (3) a structured SR-SEI reporting architecture that transforms host community relations from a liability into a demonstrable value story; and (4) first-mover positioning in a regulatory environment that will inevitably formalize. The frameworks are not prescriptive — they are designed to be adopted incrementally, beginning with Scope 1 launch emissions accounting and SR-SEI baseline measurement, then expanding as methodologies mature.

N50 Impact invites collaboration with launch operators, space resource companies, standards bodies including ISO and the Gold Standard Foundation, NASA, the FAA, and policymakers to pilot and validate the SLCAS and SR-SEI frameworks at the operational level. The data infrastructure, verification architecture, and credit registry systems required are already operational in terrestrial carbon markets. Adapting them for the space industry is not a research question — it is an implementation challenge that can begin immediately.

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