

# Introducing the Space Footprint: A Novel Metric for Sustainable Space Operations

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The Space Footprint is introduced as an innovative indicator for assessing space sustainability, akin to terrestrial concepts such as ecological and water footprints. This novel metric evaluates the carrying capacity and utilization of orbital space, a finite common resource surrounding Earth. The Space Footprint employs the formula  $C=f(\text{NATSEO})$ , which integrates the population size of space objects (N), environmental attributes of the orbital realm (A), technological innovations (T), societal ramifications (S), ecological impacts (E), and operational efficiencies (O) to holistically assess orbital sustainability.

This method transcends the mere quantification of space objects by considering their operational dynamics, potential for debris generation, equitable access to orbital resources, and cumulative impacts on the space environment. By focusing on Geostationary Orbit (GEO), this study operationalizes the Space Footprint through a case study that demonstrates its applicability in guiding sustainable practices, optimizing resource utilization, and informing policy decisions. The insights derived from this research are pivotal for developing strategies that harmonize technological advancement with the conservation of the orbital environment, ensuring the long-term viability and safety of space endeavors for current and future generations.

The Space Footprint metric evaluates key parameters to provide a nuanced understanding of space sustainability. Population size (N) reflects the density of satellites and debris, influencing collision risks. Environmental attributes (A) account for altitude, gravitational variations, radiation levels, and space weather impacts. Technological advancements (T) encompass station-keeping abilities, debris mitigation, in-orbit servicing, and end-of-life strategies, paralleling technological improvements that enhance sustainability on Earth. Social impacts (S) address equity, collaboration, and access, mirroring sustainable development frameworks. Ecological considerations (E) evaluate impacts on Earth's upper atmosphere, astronomical observations, and re-entry risk management. Operational efficiencies (O) focus on effective space traffic management, collision avoidance, and optimized response to space weather warnings.

The case study on GEO highlights the indicator's capacity to assimilate diverse data streams, facilitating simulation and scrutiny of varied orbital resource utilization scenarios. This approach aims to optimize and preserve orbital resource amidst escalating space debris, large constellation

deployments, and their longterm environmental repercussions. The Space Footprint can guide sustainable practices and inform policy and strategic decisions in orbital resource management. Future research will extend the application of the Space Footprint to other critical orbital regions like Low Earth Orbit (LEO) and Medium Earth Orbit (MEO), potentially necessitating methodological adaptations to accommodate the distinct characteristics of each orbital domain.

The Space Footprint metric, by providing a detailed and dynamic picture of the orbital environment, empowers policymakers, industry leaders, and international bodies to make informed decisions. This comprehensive approach is pivotal in guiding the development of policies and practices that ensure the long-term viability of space as a resource for humanity, operationalizing the theoretical framework into actionable insights.

**Keywords:** Space Footprint, Geostationary Orbit, Space Sustainability, Orbital Resource, Satellite Management, Space Debris

## 1. Introduction: Sustainability Challenges in Geostationary Orbit

Geostationary Orbit (GEO), situated approximately 35,786 km above Earth's equator, remains one of the most strategically valuable orbital regions for satellite operations. Its fixed position relative to the Earth's surface enables persistent communication, weather monitoring, and broadcasting services—making it a finite and highly coveted orbital shell. However, as technological dependence on GEO continues to expand, the long-term sustainability of this region is facing increasing strain from a combination of crowding, non-compliance with disposal guidelines, and persistent orbital debris.

Unlike Low Earth Orbit (LEO), where atmospheric drag naturally removes defunct objects over time, GEO lacks significant natural cleansing forces. Satellites that reach end-of-life but are not properly relocated to graveyard orbits may remain in GEO almost indefinitely, contributing to long-term congestion and increasing the likelihood of collision risks, orbital drift, and radio-frequency interference. Furthermore, even when disposal maneuvers are executed, deviations in final orbit altitude and inclination can result in long-term instability or re-entry into the protected GEO region.

Existing sustainability frameworks and tools, such as the 25-Year Rule, the Space Sustainability Rating (SSR), and ESA's MASTER model, have been instrumental in advancing debris mitigation strategies. However, these approaches often fall short in addressing the cumulative and persistent nature of sustainability challenges in GEO. Many current models are either compliance-based—focusing on whether a satellite follows best practices—or narrowly scoped to specific orbital dynamics, thereby lacking the holistic and dynamic analysis needed to assess system-wide strain in GEO.

In this context, there is a critical need for a new generation of sustainability indicators that go beyond mission-level evaluations and instead quantify the aggregate impact of all human activities in a given orbital regime. This paper introduces the Space Footprint (SF) model as a novel metric that integrates population size (N), environmental attributes (A), technological advancements (T), and operational efficiencies (O) to evaluate the sustainability of orbital regions. While the SF model

was originally developed and stress-tested in Low Earth Orbit (LEO) contexts, as presented in [1], this study applies it to Geostationary Orbit (GEO), demonstrating its adaptability to different orbital environments and its potential for informing sustainable practices and policy interventions at the system level.

By focusing on the unique conditions of GEO, this paper aims to extend the applicability of the Space Footprint and provide a dynamic framework that reflects the long-term viability of orbital operations. Through simulation and scenario analysis, we assess how technological, operational, and environmental factors interact to shape the sustainability trajectory of the GEO regime. In doing so, this work contributes to the broader conversation on orbital resource management and the urgent need for robust, scalable sustainability metrics.

## 2. The Need for a Holistic Orbital Sustainability Indicator

Despite decades of progress in orbital debris tracking and mitigation guidelines, the global space community continues to lack a unified, quantitative indicator capable of assessing the cumulative sustainability of orbital regions. Existing tools such as ESA's MASTER model and the Space Sustainability Rating (SSR) provide valuable technical or mission-level assessments, but they do not quantify the long-term system-wide strain that accumulates in critical orbital zones like Geostationary Orbit (GEO). As a result, policymakers, satellite operators, and regulators face persistent uncertainty when attempting to assess the health, resilience, or degradation of the orbital commons.

Most current frameworks rely on compliance-based metrics—e.g., whether operators dispose of satellites properly or follow collision avoidance protocols. While essential, these approaches focus on behavior rather than impact, offering no clear sense of whether the overall orbital environment is improving, stabilizing, or deteriorating. In GEO, this limitation is especially critical: even a small number of non-compliant actors can lead to long-term consequences due to the near permanence of objects in this region. Unlike Low Earth Orbit, where atmospheric drag gradually clears debris, GEO lacks natural cleansing mechanisms, making it more sensitive to small, cumulative deviations from best practices.

The Space Sustainability Rating (SSR), developed through a collaboration between ESA, the World Economic Forum, and MIT, represents a promising step in incentivizing responsible space behavior. However, its structure remains mission-specific and does not scale to evaluate sustainability at the regime level [2]. Similarly, ESA's MASTER tool models population evolution and fragmentation probabilities based on historical data, but it was not designed to express sustainability as a single impact-driven metric [3]. Carrying capacity models—attempts to define a theoretical limit for the number of satellites in an orbit—also fail to capture the dynamic interactions between debris growth, mitigation technologies, and evolving traffic patterns [4].

The absence of a system-level indicator hampers strategic decision-making. Without a quantitative way to evaluate the collective impact of human activity in GEO, there is no clear signal for when sustainability tipping points are being approached—or exceeded. Drawing from terrestrial

environmental indicators such as the ecological and water footprints, this paper proposes the Space Footprint (SF) as a new class of orbital sustainability metric. Originally introduced and validated in a Low Earth Orbit context [1], the SF model is designed to reflect the aggregate strain imposed by orbital activity, modulated by both environmental and human-influenced factors.

By incorporating four key dimensions—Population Size (N), Environmental Attributes (A), Technological Innovations (T), and Operational Efficiencies (O)—the Space Footprint goes beyond regulatory compliance to measure how sustainable an orbital region truly is. The next section will reintroduce these parameters within the context of GEO, demonstrating how their behavior and weighting must adapt to reflect the distinct physical and operational dynamics of this high-altitude region.

### 3. Deriving the Space Footprint Metric: Core Parameters (NATO)

The Space Footprint (SF) metric is designed to capture the cumulative sustainability burden of orbital activity by integrating both strain-inducing and mitigating factors into a single, dynamic indicator. It draws inspiration from terrestrial sustainability tools such as the ecological footprint but is adapted for the unique physical, operational, and policy challenges of the orbital environment. The SF model achieves this through four core parameters: Population Size (N), Environmental Attributes (A), Technological Innovations (T), and Operational Efficiencies (O). Together, these parameters form the basis of the SF equation:

$$SF = \frac{N \cdot A}{T \cdot O} \quad (1)$$

Each parameter in this expression captures a distinct aspect of orbital sustainability, and their combined effect reflects the system-level strain imposed on a given orbital regime.

#### 3.1. Population Size (N)

The parameter N represents the total number of resident space objects in a given orbital shell. It includes active satellites, defunct spacecraft, and trackable debris fragments above a standard size threshold (typically  $\geq 10$  cm in GEO). In the context of Geostationary Orbit, where debris removal is not naturally assisted by atmospheric drag, even a modest increase in population density significantly elevates long-term collision risk and radio-frequency interference.

$$N = N_{\text{active}} + N_{\text{inactive}} + N_{\text{debris} \geq d} \quad (2)$$

Because orbital persistence in GEO can span centuries, N acts as a strong driver of cumulative strain in the SF model. Future refinements may also include mass, cross-sectional area, or radar reflectivity as weighting factors.

## 3.2. Environmental Attributes (A)

The A parameter accounts for natural forces that influence object stability and debris longevity. In Low Earth Orbit, atmospheric drag is the dominant force accelerating orbital decay. However, in GEO, A is governed by factors such as solar radiation pressure, gravitational perturbations (e.g., from the Moon and Sun), and resonant drift zones.

For GEO, A is defined as:

$$A = 1 + G + S \quad (3)$$

Where:

- G represents gravitational perturbation-induced drift,
- S reflects solar radiation pressure impacts on uncontrolled objects

In practical terms, A is generally greater than 1 in GEO due to these destabilizing effects. Although these forces do not lead to orbital decay in the same way as drag in LEO, they do contribute to uncontrolled object drift and complicate station-keeping and graveyard orbit management.

## 3.3. Technological Innovations (T)

The T parameter measures the effectiveness of debris mitigation technologies and end-of-life strategies. In GEO, this includes:

- Reliable graveyard orbit maneuvers,
- Fuel allocation for end-of-life disposal,
- Inclusion of autonomous passivation systems.

$$T = \alpha \cdot \sigma \cdot \mu \quad (4)$$

Where:

- $\alpha$  is the adoption rate of mitigation technologies,
- $\sigma$  is the success rate of those technologies when implemented,
- $\mu$  is an impact factor representing how much sustainability benefit is derived from each successful application.

Given that not all satellites in GEO have the same maneuvering capabilities or redundancy systems, T can vary significantly across operators and mission types. The model applies logarithmic scaling to reflect diminishing returns—once high adoption is achieved, further gains require breakthrough innovation or systemic change.

### 3.4. Operational Efficiencies (O)

The O parameter evaluates real-time strategies that reduce collision probability and operational risk, particularly for active spacecraft. In GEO, this includes:

- Station-keeping precision,
- Coordination of orbital slot assignments,
- Use of Space Situational Awareness (SSA) tools for conjunction analysis.

$$O = \beta \cdot \gamma \cdot \delta \quad (5)$$

Where:

- $\beta$  = implementation rate of active operations (e.g., autonomous maneuvering),
- $\gamma$  = operational success factor (how well these measures perform),
- $\delta$  = observation quality factor (based on access to tracking and ephemeris data).

As with T, the O parameter benefits from logarithmic capping to prevent unrealistically optimistic outcomes in the model. High operational efficiency cannot fully offset a congested or poorly governed environment.

Together, the NATO structure allows the SF model to represent both strain (via *N* and *A*) and mitigation (via *T* and *O*) within a unified sustainability indicator. In the next section, we apply this model specifically to GEO conditions and assess how each parameter behaves in the absence of natural debris removal, under varying levels of compliance and operational coordination.

## 4. Parameter Adaptation for the GEO Context

The utility of the Space Footprint (SF) model lies in its adaptability to different orbital regimes. While its core structure—integrating population size (*N*), environmental attributes (*A*), technological innovations (*T*), and operational efficiencies (*O*)—remains consistent, the behavior and interpretation of each parameter must be adjusted to reflect regime-specific dynamics. In the case of Geostationary Orbit (GEO), distinct physical conditions, usage patterns, and policy considerations necessitate parameter redefinition and recalibration.

### 4.1. Population size (N) in GEO

In GEO, even modest population growth introduces significant sustainability risk due to the absence of natural decay mechanisms. While LEO tolerates larger populations through continuous atmospheric drag-induced object removal, GEO accumulates long-lived debris and inactive satellites indefinitely unless they are actively removed or relocated to disposal orbits.

Most tracked objects in GEO consist of:

- Operational satellites (~500+),
- Inactive or passivated spacecraft,
- Break-up fragments from explosions or failed passivations,
- Non-compliant objects drifting within or near the protected GEO belt.

The N parameter in GEO should therefore be interpreted less as a raw count and more as an accumulated burden, where every object left unmanaged adds to persistent orbital risk over a century-scale horizon. Weighting by area-to-mass ratio, object size, or drift rate may offer more precise future refinements.

## 4.2. Environmental Attributes (A) in GEO

GEO lacks atmospheric drag—the dominant natural cleansing force in LEO—making the A parameter inherently destabilizing in this regime. The primary contributors to environmental influence in GEO include:

- Solar radiation pressure, which affects uncontrolled objects, causing longitudinal drift or liberation around stable points.
- Gravitational perturbations (especially from the Moon and Sun), which drive slow inclination changes and pose station-keeping challenges.
- Drift resonance zones, where uncorrected orbits lead to cumulative angular displacement over years or decades.

Thus,  $A > 1$  in GEO generally reflects the persistence-enhancing nature of the environment, where natural forces make sustainable operations harder rather than easier. Unlike in LEO, where drag is beneficial, GEO's environmental dynamics exacerbate orbital instability for inactive or derelict objects

## 4.3. Technological Innovations (T) in GEO

In GEO, the T parameter reflects the adoption and effectiveness of technologies such as:

- End-of-life maneuvers to graveyard orbits,
- Reliable fuel budgeting and propulsion systems,
- Autonomous passivation and deorbit devices (rare in GEO but emerging).

While most operators nominally commit to IADC disposal guidelines (e.g., re-orbiting to 300 km above GEO), compliance rates vary significantly—especially among legacy missions, small operators, or actors with incomplete maneuver capabilities.

Notably, a failed disposal in GEO results in indefinite congestion, making the impact factor ( $\mu$ ) especially high in this regime. Future SF implementations may include scenario-specific weighting for "permanent" non-compliance, where the object's orbital persistence spans generations.

## 4.4. Operational Efficiencies (O) in GEO

The O parameter in GEO emphasizes:

- Precise station-keeping to prevent longitudinal drift,
- Collision avoidance maneuvers between co-located satellites (especially for satellites near hotspots like 75°E or 105°W),
- Coordination through Space Situational Awareness (SSA) and Space Traffic Management (STM) platforms.

A critical distinction in GEO is that the number of actively maneuverable objects is relatively small, while a growing number of uncontrolled or passivated objects remain in the protected region or just outside it. Thus, high O values are only meaningful if coordination covers both active and passive threats—a challenge exacerbated by poor observability of small or dark objects in GEO.

Additionally, lack of transparency in ephemeris sharing between some international operators further reduces  $\delta$  (observation quality factor) in certain orbital zones, even when high-fidelity ground assets exist.

By recalibrating the SF model’s core parameters to align with the unique challenges of GEO, this study enables a more accurate and policy-relevant measurement of sustainability in this critical regime. The next section applies these adaptations in a series of scenario simulations to explore how different disposal strategies, compliance levels, and operational behaviors influence the long-term sustainability of GEO

## 5. GEO Scenario Simulation and Space Footprint Analysis

To illustrate the applicability of the Space Footprint (SF) model in Geostationary Orbit (GEO), we conduct a set of scenario-based simulations that explore how orbital sustainability evolves under varying levels of compliance, technological adoption, and operational coordination. These scenarios are not merely illustrative—they aim to quantify the long-term implications of different governance and engineering decisions within a regime characterized by orbital permanence and high commercial value.

Each scenario uses a simplified but representative implementation of the SF equation:

$$SF_{\text{GEO}} = \frac{N \cdot A}{T \cdot O} \quad (6)$$

Where parameters have been adapted per Section 4 to reflect GEO-specific conditions.

## 5.1. Baseline GEO Scenario: Current Conditions

This scenario represents the present-day state of GEO operations, based on:

- $N = 1,200$  (includes active satellites, defunct spacecraft, and catalogued debris  $\geq 10$  cm),
- $A = 1.3$ , representing moderate destabilization from solar radiation and gravitational perturbations,
- $T = 1.0$ , reflecting  $\sim 85\%$  compliance with re-orbiting guidelines,
- $O = 0.9$ , representing relatively high station-keeping coordination among major operators.

$$SF_{\text{baseline}} = \frac{1200 \cdot 1.3}{1.0 \cdot 0.9} \approx 1,733$$

This baseline Space Footprint serves as a reference for comparative analysis. It indicates a non-negligible but stable sustainability burden, primarily due to the accumulation of long-lived objects.

## 5.2. Non-Compliance Scenario: EOL Maneuver Failures

This scenario explores the long-term impact of reduced compliance with end-of-life re-orbiting guidelines:

- $N = 1,400$  (includes additional failed graveyard transfers and fragments),
- $T = 0.5$ , reflecting only  $\sim 50\%$  compliance with re-orbiting and passivation procedures.

$$SF_{\text{non-compliant}} = \frac{1400 \cdot 1.3}{0.5 \cdot 0.9} \approx 4,044$$

This nearly  $2.3\times$  increase in SF from baseline highlights the long-term risk of non-compliance in a regime without natural debris removal. The sustainability trajectory under this scenario is significantly degraded and would likely trigger risk-averse behaviors such as increased satellite separation or slot abandonment.

## 5.3. Enhanced Technology Scenario: Universal Compliance

Here, we explore a best-case future where nearly all actors adopt reliable EOL technologies:

- $T = 1.8$ , reflecting high adoption and success rates,
- $O = 1.0$ , assuming effective coordination and universal ephemeris sharing.

$$SF_{\text{tech-optimized}} = \frac{1200 \cdot 1.3}{1.8 \cdot 1.0} \approx 867$$

This reduced SF value reflects a stabilized GEO environment. Importantly, however, the model shows diminishing returns—even universal compliance does not eliminate sustainability concerns entirely, due to the long-term presence of older, unremediated objects.

## 5.4. Drift Cascade Scenario: Passive Object Accumulation

In this stress-test scenario, a growing number of non-maneuverable objects slowly drift into GEO due to station-keeping failure or inaccurate disposal:

- $N = 1,800$ ,
- $T = 0.6$ , reflecting degraded disposal reliability,
- $O = 0.7$ , due to limited predictability and poor observation of passive objects.

$$SF_{\text{drift-cascade}} = \frac{1800 \cdot 1.4}{0.6 \cdot 0.7} \approx 6,000$$

This worst-case trajectory indicates a progressively degrading regime where even active operators must expend increasing effort to avoid uncontrolled objects. The SF acts as an early-warning signal of a regime trending toward long-term congestion.

## 5.5. Comparative Visualization

Figure 1 presents a comparative bar chart of Space Footprint (SF) values across key GEO sustainability scenarios, including a baseline, reduced compliance, enhanced mitigation, and passive drift accumulation. This visualization highlights the widening sustainability gap resulting from policy inaction versus proactive mitigation strategies. The chart helps illustrate how specific management behaviors correlate with measurable orbital consequences, providing decision-makers with actionable insights.

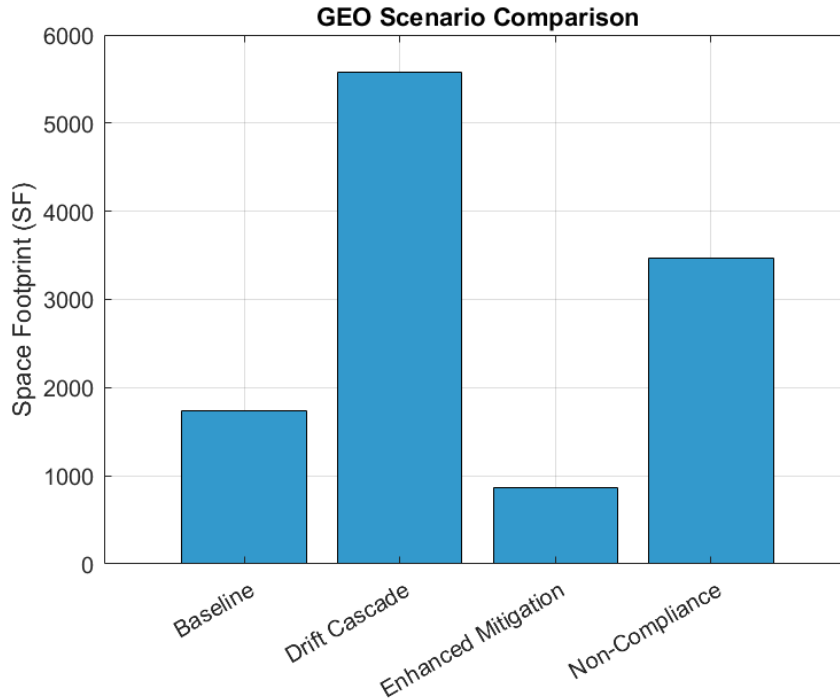


Figure 1: Comparative Space Footprint (SF) Values for Key GEO Scenarios.

These scenarios underscore the power of the SF metric in providing quantitative insights into the sustainability trajectories of GEO under varying management strategies. In the next section, we interpret these findings in the context of orbital governance and regulatory design, demonstrating how SF values can inform practical space policy interventions

## 6. Findings and Implications for GEO Governance

The scenario analysis conducted in Section 5 demonstrates how the Space Footprint (SF) model can quantify the sustainability trajectory of Geostationary Orbit (GEO) across diverse operational, technological, and policy contexts. Several key findings emerge, each with direct implications for space governance:

### 6.1. The Risk of Passive Accumulation

The most critical insight is that even small deviations in compliance or coordination can result in long-term sustainability deterioration in GEO. Due to the near-permanence of resident objects, passive accumulation—whether through failed end-of-life (EOL) maneuvers, expired satellites, or fragmentation debris—can quickly lead to nonlinear increases in SF values. This is consistent with previous findings in population dynamics models but now presented through a single, interpretable metric. Importantly, the drift cascade scenario reveals that orbital degradation in GEO may manifest not as sudden collisions but as gradual operational instability, complicating slot management and ephemeris forecasting over decades.

## 6.2. Regulatory Tools Need Impact-Based Indicators

Current regulatory frameworks such as the IADC disposal guidelines or the ITU's orbital slot assignments remain compliance-focused, but lack feedback mechanisms for assessing whether aggregate behavior is trending toward or away from sustainability. The SF model provides this missing layer by integrating real-world data—object counts, compliance trends, maneuver success rates—and expressing the evolving regime-level risk in a single number. As such, SF can serve as:

- A monitoring tool to track the sustainability health of the GEO regime over time,
- A policy benchmark to assess the effectiveness of new mitigation mandates,
- A decision-support metric for agencies allocating slots or regulating EOL maneuvers

## 6.3. Technology is Not a Substitute for Coordination

While technological adoption (e.g., autonomous graveyard maneuvers) substantially lowers SF values, the model confirms that operational efficiency (O) plays an equally vital role. Even in high-technology scenarios, poor coordination—especially lack of data sharing or opaque slot behavior—results in elevated SF scores. This finding supports recent calls for internationally harmonized Space Traffic Management (STM) frameworks, where shared situational awareness and maneuver protocols are essential.

## 6.4. The SF Model Supports Multi-Stakeholder Dialogue

Unlike proprietary or black-box sustainability tools, the SF model is transparent, adaptable, and traceable, allowing stakeholders—including regulators, commercial operators, and international bodies—to evaluate orbital health using a shared vocabulary. The model's clarity also enhances accountability: rising SF values can be directly tied to specific behaviors, such as underreported failures or low compliance clusters. This creates opportunities for incentive-based governance, where sustainability-linked insurance, spectrum access, or financing mechanisms reward operators who actively reduce the SF burden

In summary, the SF model does not replace existing guidelines or mission-level ratings—it complements them by offering a system-level sustainability indicator. In the context of GEO, it highlights the long-term costs of regulatory inaction, fragmented coordination, and technological unevenness. As the orbital environment continues to grow more competitive and contested, tools like the Space Footprint may prove essential in building a transparent, accountable, and future-ready orbital governance architecture.

# 7. Conclusions and Future Work

This paper has introduced the Space Footprint (SF) as a novel and adaptable metric for quantifying orbital sustainability, focusing on its application to Geostationary Orbit (GEO). Through the integration of four core parameters—Population Size (N), Environmental Attributes (A), Technological Innovations (T), and Operational Efficiencies (O)—the model captures both the

cumulative burden and mitigation potential of human space activity. By tailoring these parameters to the GEO regime, where orbital persistence, passive drift, and coordination challenges dominate, the SF model offers a fresh approach to evaluating long-term sustainability.

Scenario-based simulations demonstrate how small variations in compliance or coordination can lead to significant increases in SF values, signaling future risks even in the absence of catastrophic collisions. The results reveal that sustainability in GEO is not just a function of satellite numbers but also a reflection of behavioral patterns, governance quality, and technological asymmetries. By providing a clear, interpretable output that reflects dynamic orbital conditions, the SF metric fills a critical gap in existing space governance toolkits.

Looking ahead, several avenues of work will extend the utility and precision of the SF model:

- **Empirical validation:** Applying the model retrospectively to historical events in GEO (e.g., failed disposal maneuvers, break-up events) will help calibrate the real-world sensitivity of each parameter.
- **Real-time integration:** By linking the model to live orbital object databases (e.g., DISCOS, Space-Track, and commercial SSA platforms), the SF could be deployed as a live monitoring dashboard, offering regime-wide sustainability updates to regulators and operators.
- **Cross-regime comparisons:** The GEO-focused formulation presented here is a stepping stone toward a comparative SF framework for LEO, MEO, and beyond—enabling sustainability benchmarking across regimes and mission types.
- **Scenario planning and policy testing:** The SF model can serve as a decision-support tool to simulate the potential impacts of regulatory changes (e.g., mandatory graveyard maneuvers, international STM protocols) before they are implemented.
- **Inclusion of societal and ecological extensions:** While this study has focused on operational and technological factors, future research may include Societal (S) and Ecological (E) dimensions, such as equitable access to orbital slots and environmental impacts from re-entries and reflectivity.

In conclusion, the Space Footprint offers a scalable and interpretable metric for tracking and guiding sustainable behavior in space. Its application to GEO demonstrates its flexibility and relevance for orbital regimes that pose distinct policy and engineering challenges. As space becomes more economically vital and operationally crowded, metrics like the SF will be indispensable for building the global norms, incentives, and infrastructure needed to ensure the long-term viability of orbital resource.

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