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Understanding Citizen Science: Insights from the 2024/2025 OpenSky Network User Survey

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Abstract
The OpenSky Network has grown into one of the largest community-driven air traffic surveillance infrastructures worldwide. While its data are widely used in research, comparatively little is known about the individuals who maintain the sensor network. In late 2024 to early 2025, we conducted the first large-scale user survey of OpenSky Network members to better understand the demographics, motivations, and barriers associated with participation. This paper presents key findings from more than 500 responses, highlighting who contributes to OpenSky and why, and what prevents others from becoming active feeders. The collected data show that participants are predominantly well-educated, above-median-income males from Western countries, with an approximate average age of 50 years. Their primary motivation is contributing to research, despite limited knowledge of the specific research projects. Cost is the main barrier to participation, particularly in underrepresented regions, whereas disinterest and environmental concerns deter adoption in other areas.

1. Introduction

A specific and underexplored form of scientific crowdsourcing is *stationary citizen sensing* (SCS), where individuals install and maintain fixed sensors that continuously transmit data to a central network for collection and analysis. Such networks generate global, high-resolution, real-time data and are particularly common in air quality, weather, radio spectrum, and air traffic monitoring. Beyond research [1], SCS data serve numerous applications, including policy development [2], investigative journalism [3], and even military intelligence [4]. Recent studies also highlight its value in detecting Global Positioning System (GPS) spoofing and jamming incidents affecting civil aviation. [5]

Despite their growing importance, little is known about the social and behavioral mechanisms driving SCS participation. While the technical process of data collection is well understood, the human factors, i.e., who participates, why, and under what conditions, remain largely unexplored. Understanding these dynamics can improve network reliability, guide expansion strategies, and assess the feasibility of new projects.

The OpenSky Network (OSN) [6] is one such SCS initiative, focused on air traffic surveillance data, enabling over 800 academic publications with their data (as of March 2026), including the yearly OpenSky Reports ranging from current topics such as cyber security to contrails and emissions

[7, 8, 9, 10, 11, 12, 13, 14, 15, 16]. OSN is a global crowdsourced flight-tracking network where volunteers operate sensors that receive Automatic Dependent Surveillance–Broadcast (ADS-B)[1] and Mode Select (Mode S)[2] signals. Its open-science mission and accessible membership base make it a representative SCS case. Understanding who contributes to OpenSky, and why, is vital for sustaining active membership growth and ensuring balanced geographic coverage of the provided research data. We therefore launched a dedicated survey of OSN users in December 2024.

Three aspects render OSN particularly suitable for investigation. First, unlike most citizen science projects, it has no single research objective but its data are available for diverse, initially unknown studies. This allows testing whether previously identified motivation patterns hold in a multi-purpose context. Second, OSN requires participants to purchase, set up, and maintain dedicated sensors, implying higher entry costs than typical crowdsourcing models relying on smartphones or manual inputs. Third, the network is embedded in a pre-existing community of aviation enthusiasts such as plane spotters [19, 20]. While not entirely unique in this area, the presence of such hobbyist communities creates a supportive environment which encourages participation. Specifically for SCS, the potential for synergy between similar networks is quite significant due to interoperable receivers that enable data sharing across multiple platforms.

To discover who participates in such SCS and for what reasons, this project conducts a comprehensive survey of OSN members, examining demographic profiles, motivations for participation, and barriers to active involvement.

Our work deepens understanding of participation patterns in stationary citizen sensing projects and extends existing citizen science research to a novel technical and organizational setting.

2. Literature Review

Empirical research on citizen science and crowdsourcing consistently shows that participants do not accurately represent the general population. Studies report an overrepresentation of well-educated, above-median-income groups [21, 22, 23, 24]. Gender balance is uncommon: women are for example underrepresented in Volunteered Geographic Information (VGI) projects like OpenStreetMap [25, 26] or Wikipedia [27], while platforms such as Amazon MTurk show the opposite pattern [28]. Age patterns are mixed: participants often average around fifty years [29, 30], but projects with digital interfaces tend to attract younger groups [22, 31].

Motivational studies on participants are equally extensive and can be grouped by level of engagement, following Haklay's four-stage typology [32] of citizen science projects. At the low end, *crowdsourcing* involves providing data or computing power with minimal cognitive input, while *extreme citizen science* gives citizens full control of research design and execution. Most studied projects lie between these extremes, namely in the *distributed intelligence* category, where participants classify or actively collect data. Across such projects in the areas of astronomy, ecology, health, and VGI [33, 34, 35, 36], intrinsic motivations such as curiosity, learning, and contributing to science dominate.

Low-engagement projects - like distributed computing or citizen sensing - show only slightly different patterns. Participants in such initiatives emphasize altruistic motives and support for the respective underlying causes [37, 38, 39, 40]. Even when financial incentives are present, as it often

[1]A surveillance technology in which an aircraft automatically broadcasts its identity, position (derived from onboard navigation systems such as GPS/GNSS), and other flight data to ground stations and other equipped aircraft without requiring radar interrogation.[17]

[2]A secondary surveillance radar (SSR) system that enables selective interrogation of aircraft using a unique address, improving identification and altitude reporting, and providing a data link foundation used by extended services such as ADS-B.[18]

is in classical crowdsourcing initiatives, intrinsic and reputational rewards remain strong motivators [41, 42, 43].

To enhance the comparability of research on participation motivations, Levontin et al. [44] proposed the *Citizen Science Motivation Scale* (CSMS), grounded in Schwartz's theory of basic human values [45, 46] and enriched by empirical results. Schwartz's model arranges twelve universal values along two bipolar axes: *openness to change vs. conservation* and *self-transcendence vs. self-enhancement.* A simplified version is shown in Fig. 1. The CSMS takes this as a point of departure and maps 280 empirically identified motivators onto it. Based on motivators that do not fit into Schwartz's framework it adds four values. These are "help with research" aligned with self-transcendence, "social expansion" aligned with openness to change, "routine" aligned with conservation, and "teaching" as a stand-alone category. This provides a comprehensive, theory-based framework for cross-project comparison.

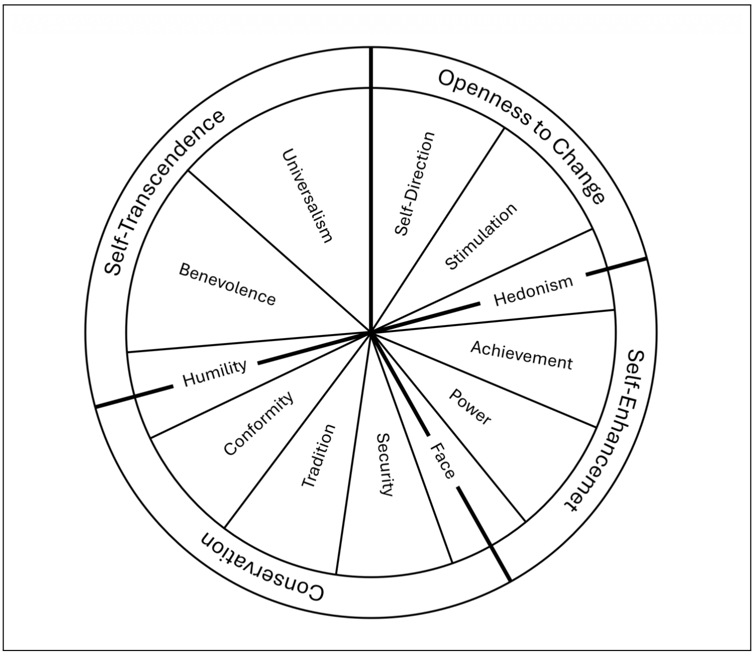

Figure 1. Simplified representation of Schwartz's value structure, showing twelve basic values arranged along two bipolar dimensions (adapted from [46]).

A complementary approach by Budhathoki [35] identified twenty-four motivational categories for VGI contributors, derived empirically from volunteering, leisure, and knowledge-production literature. While less theory-driven, it captures domain-specific motivators for digital mapping and data-sharing communities underrepresented in the CSMS model. Both frameworks inform the analysis of motivations within the present study.

Research on non-participation remains scarce. Existing work [47, 48, 49] highlights the perceived lack of time, physical ability, or (technical) skills as primary barriers.

Few studies have addressed networks comparable to OSN. Given OSN's unique combination of open data, hobbyist community, and upfront hardware investment, participation motives and deterrents may differ substantially from those found in other citizen science projects.

3. Theory and Hypotheses: Understanding OSN Members

Existing studies offer valuable insights into who participates in citizen science and crowdsourcing initiatives and why. This section contextualizes those findings within the OSN and formulates four hypotheses addressing demographic, motivational, and discouraging factors.

3.1 Demographic and Socioeconomic Factors

Empirical studies consistently show that participants in citizen science projects tend to be well-educated, above-average-income individuals from developed regions. Assuming that sensor location correlates with its owner's residence, the distribution of OSN sensors similarly indicates a dominance of contributors from Europe and North America. This can be derived more or less directly from OSN's coverage over time. [1]

Gender imbalance is also expected: men are likely to outnumber women, consistent with related hobbies such as plane spotting [19]. In addition, participants are expected to be younger than 50 years old, reflecting the digital competence required to install and maintain receivers. Because OSN participation (whether active or passive) demands little time, employment is not expected to be a factor driving up average age.

> **H1:** Most OSN participants are well-educated, above-median-income males below the age of 50, living in the developed nations of the Global North.

3.2 Motivational and Discouraging Factors

Levontin et al. [44] present a comprehensive framework of possible motivations for citizen science participation. Applying their model to OSN, two factors stand out as particularly relevant, given the network's unique characteristics.

Lack of a specific research goal. Unlike most citizen science projects, OSN does not pursue a single defined research objective which participants anticipate contributing to when they join the network. Rather, data is provided for diverse purposes, including but not exclusive to research. However, prior studies suggest that clear project goals are powerful motivators. Due to the lack of this clear research goal, OSN members are expected to place less emphasis on "helping with research" as a central reason for participation.

> **H2:** Helping with research is not among the main factors motivating individuals to operate a sensor for OSN.

Existing community engagement. OSN benefits from a large, pre-existing community of aviation enthusiasts, i.e., plane spotters and users of other flight-tracking platforms, who often already possess compatible equipment. Because receivers can feed multiple networks, many OSN participants likely joined after already being active elsewhere. Routine, indicating pre-existing involvement in similar activities is thus expected to play a major role.

> **H3:** Routine—being already engaged in a similar activity—is among the strongest motivators for operating a sensor for OSN.

Financial barriers to active participation. A further question concerns why many OSN members remain passive. Previous research highlights time and skill constraints as common deterrents.

For SCS, however, an additional obstacle arises: the initial financial investment required for hardware setup. Unlike many citizen science projects that are not reliant on or supply participants with equipment, OSN depends on volunteers to purchase their own sensors. This cost barrier likely prevents some interested passive members from becoming active.

> **H4:** The financial effort required to become an active member of OSN is among the most significant reasons individuals remain passive in the network.

4. Surveying OpenSky

We design an online survey of all OSN members to examine the community's demographic composition, motivations for maintaining an ADS-B receiver, and reasons for abstaining. Using surveys to study participation in citizen science is standard practice. [50] At the time of the survey, OSN comprised roughly 50,000 registered members, about 5,000 of whom operate(d) at least one sensor.

Ethical approval was granted by the ETH Zurich Ethics Committee (Application No. ETHICS-403). The survey was hosted on *Qualtrics*, tested with nine pilot participants, and optimized for different devices. Recruitment occurred via the OSN newsletter and homepage as well as the OSN Discord group. To increase participation, an ADS-B receiver kit (Raspberry Pi + antenna) was raffled among respondents, an incentive expected to attract non-sensor owners in particular. The survey was open for ten weeks, starting on December 22, 2024.

For representativeness, a 90% confidence level with a 5% margin of error required at least 258 active sensor owners and 270 passive, non-sensor-owning respondents, though all members were encouraged to participate. The questionnaire began with demographic questions and then branched into two paths: one for sensor owners (motivations) and one for non-owners (deterrents). Except for age, questions were non-mandatory. The complete survey instrument is provided in the Appendix.

4.1 Demographic and Socioeconomic Questions

To address **H1**, participants provided information on age, gender, residence, education, occupation, and income. Two additional questions asked about proximity to airports and employment in the aviation sector. Because OSN is international, income was measured subjectively by asking respondents to place themselves within national income quintiles, following the World Values Survey approach. [51] This relative measure avoids conversion barriers while capturing socioeconomic position. [52]

Education was classified using the 2011 International Standard Classification of Education (ISCED), condensed into eight levels from "no education" to "doctoral degree." Examples such as "years 1–6" or "licence / bachelor's degree" ensured clarity across countries. This structure facilitated consistent data collection across OSN's global membership.

4.2 Motivational Questions

The motivation module tested **H2** and **H3**. It combined elements from Levontin et al.'s CSMS [53, 44] with items from Budhathoki [35], whose work on OpenStreetMap (OSM) mirrors OSN in some key aspects: no single research goal, global reach, absence of time constraint for contributions, and visibility of individual input on a map.

Where both frameworks overlapped, similar motivational categories were merged; where they diverged, alignment followed Schwartz's value definitions [46] and item examples. Notable adjustments included:

- *Instrumentality of local knowledge*: emphasizing the sense of indispensability of one's own contribution is mapped to the "achievement" value.

- *Unique ethos*: reflecting pro open data and anti-corporate attitudes is aligned with "social universalism".
- *Meeting self-needs*: where individuals participate out of need for the content resulting from the contribution (e.g., a map) is associated with "self-direction".
- *Fun*: captured under "hedonism," with added salience from the immediate visibility of one's contributions on a live map.
- *System trust*: excluded, as it represents a prerequisite rather than an intrinsic motivation for participation.

Six of Levontin et al.'s categories found no counterpart in Budhathoki's typology, likely due to the latter's empirical, rather than theoretical origin. Consequently, Levontin's CSMS, enriched with Budhathoki's compatible items, formed the basis for OSN's motivational survey.

After merging and refinement, 64 items across 18 categories were reduced to 37 items within 15 categories (see table 3). Following Levontin et al.'s guidance, at least two items per category were retained. Redundant or overlapping items were merged, and the least relevant categories "tradition" and "stimulation–active" were removed. The live survey presented these statements as a randomized carousel with a five-point Likert scale (*not important – very important*) plus an "irrelevant" option and added one attention check statement ("If you are actively reading this, please select five.").

4.3 Deterrence Question

Respondents who indicated they did not operate a sensor were redirected to a multiple-choice question listing thirteen possible deterrents (select one to three). This section tested **H4**. The list combined literature-derived and context-specific factors, including concerns about data sharing and perceptions of local sensor saturation. An open-text "other" option captured additional reasons.

Beyond testing **H4**, this analysis helps identify low-effort strategies for converting passive members —OSN's "low-hanging fruit"—into active contributors. For example, if technical difficulty emerges as a common barrier, clearer setup documentation could effectively expand coverage.

4.4 Statistical Analysis

Demographic data were analyzed descriptively and compared between active and passive members using Mann–Whitney, χ^2, and, where necessary, Fisher's exact tests. As age was measured categorically, category midpoints were used to obtain an approximate average value.

Quality of the motivational constructs was assessed with Confirmatory Factor Analysis (CFA), a common method for assessing multi-item constructs [54]. The CFA included testing model fit, composite reliability, convergent validity, and discriminant validity [55]. Respective thresholds were chosen based on the literature. Composite reliability, informing about the internal consistency of a latent construct [56], was measured with McDonald's ω. Values of 0.7 or higher indicate good reliability [57]. Convergent validity, describing how well a category is represented by its respective items, was assessed through factor loadings ($\geq$ 0.5 acceptable, $\geq$ 0.7 ideal) and Average Variance Extracted (AVE, $\geq$ 0.5 acceptable)[57]. Factor loadings indicate the degree to which a category explains the variance of each of its corresponding items while AVE reflects how much of the variance in a construct's items is accounted for by the construct itself, relative to the total variance present in those items [56]. Discriminant validity, showing how sharply the categories can be distinguished from each other, was evaluated using a correlation threshold of 0.85 [56].

Responses failing the attention check were excluded from the motivational analysis. For each participant, category means were computed (excluding "irrelevant" responses), allowing comparison of the relative importance of 15 motivational factors. Category means ≤ 2.3 indicated low importance, 2.3–3.7 medium, and ≥ 3.7 high. Results were also compared between OSN and other networks' sensor operators to test **H2** and **H3**. For comparison, relative thresholds, based on the minimum and maximum values of the mean responses, were also included.

Finally, deterrence responses were analysed descriptively, i.e., summarized by frequency and region. Open-ended comments were analyzed qualitatively to identify emerging themes and actionable insights.

5. Results

In total, 858 individuals clicked the survey link, and 596 provided at least partial answers. Nearly 95% of responses were collected via newsletter invitations, with the remainder recruited through the OpenSky website and Discord channel. Of these, 552 completed the demographic questions, including 317 sensor owners. Given the network's size at the time, active participants were over-represented; an expected outcome given their high engagement level. While this slightly limits generalizability for passive members, the overall sample remains informative.

5.1 Demographic Factors

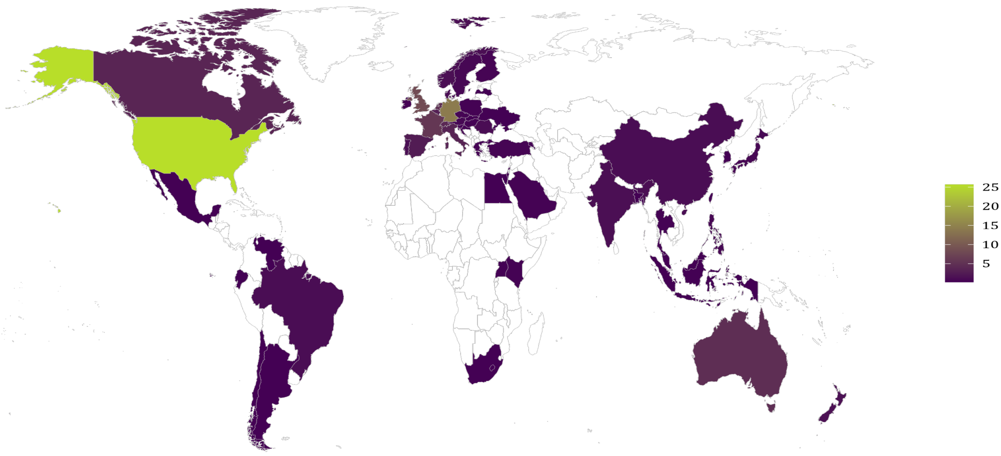

Figure 2. Participants' country of residence.

Most respondents reside in Europe or North America. 56.9% of respondents lived in Europe, 29.2% in North America, and 9.9% in East Asia and the Pacific. The remaining participants were distributed across Latin America (1.9%), South Asia (1.4%), and MENA or Sub-Saharan Africa (0.7%) (see Fig. 2). Only 22.5% reported living in rural areas, with a majority in urban or suburban living areas. Most were employed in the private sector (55.1%), with 30.2% working in aviation-related fields. Over half (51.9%) said their daily lives were at least somewhat affected by airport activity.

The findings mostly support **H1**: most OpenSky members are well-educated, above-median-income males under 50 living in developed nations. Approximately 76% hold at least a bachelor's degree, while none reported only primary education. The average income quintile reported by respondents is 3.5 and thus above median. Overall, 94% identified as male, 2.8% as female, and 3.2% preferred not to say, with slight variations conditional on sensor ownership (see Fig. 3). The approximate average

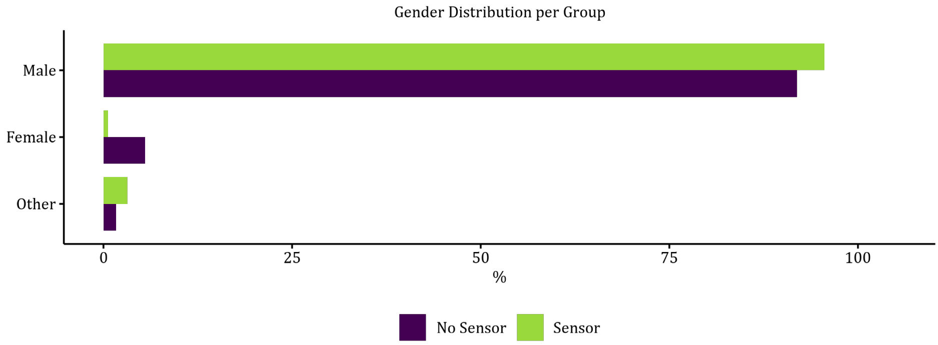

Figure 3. Participants' gender by sensor ownerhsip.

Table 1. Age distribution of OpenSky Network survey participants by sensor ownership. Median age group in bold.

Age group	No Sensor (n)	%	Sensor (n)	%
<18	0	0.00	0	0.00
18–24	13	5.53	10	3.15
25–34	27	11.49	39	12.30
35–44	52	22.13	72	22.71
45–54	42	17.87	86	27.13
55–64	56	23.83	67	21.14
65–74	39	16.60	36	11.36
>75	6	2.55	7	2.21
Mean age	49.20 (SD = 14.90, 95% CI: [48.00, 50.40])			
By group	**Mean**	**SD**	**Lower 95% CI**	**Upper 95% CI**
No Sensor	49.90	15.27	47.29	51.11
Sensor	48.90	13.80	47.56	50.84

age of respondents was 49.2 years, with an upper 95% confidence bound of 50.4, suggesting members are around, but not clearly below, 50 years. Table 1 shows the full distribution. Respondents came from 56 countries, with 25.6% from the United States. The U.S., Germany, the U.K., and France accounted for more than half (53.6%) of all responses. Only 4.4% of participants came from major emerging economies, and just 0.4% from least developed countries.

Active and passive members were broadly similar across demographic variables except for gender (Fisher's exact test), primary occupation (χ^2 test), and income (Mann–Whitney). Only two female respondents operated a sensor. While most respondents were full-time employees (62.8%), active members were more likely to be employed full-time or unemployed, whereas passive members were more often students, retired, or part-time employees. Active members' average income was 0.3 quintiles higher than that of passive members (3.6 vs. 3.3).

5.2 Motivational Factors

As shown in Table 2, 317 respondents reported operating a sensor, and 71 did so for other networks. Of these, 285 answered more than half the motivational items, and 277 valid responses remained (nine failed the attention check). CFA indicated a moderate model fit ($p(\chi^2) < 0.05$, CFI = 0.91, RMSEA = 0.04, SRMR = 0.07). Reliability and validity tests show that categories such as *face*, *social expansion*, *security*, *benevolence*, *universalism*, *help research*, and *teaching* demonstrated satisfac-

Table 2. Sensor ownership among OpenSky Network survey participants.

Sensor ownership	Frequency	%
I operate a sensor, but it does not contribute to OpenSky	71	12.86
No sensor	235	42.57
Yes, I operate an OpenSky sensor	246	44.57

tory composite reliability and convergent validity. *Conformity* and *self-direction* were acceptable but weaker, while *routine* performed poorly, lacking both internal consistency and convergent validity.

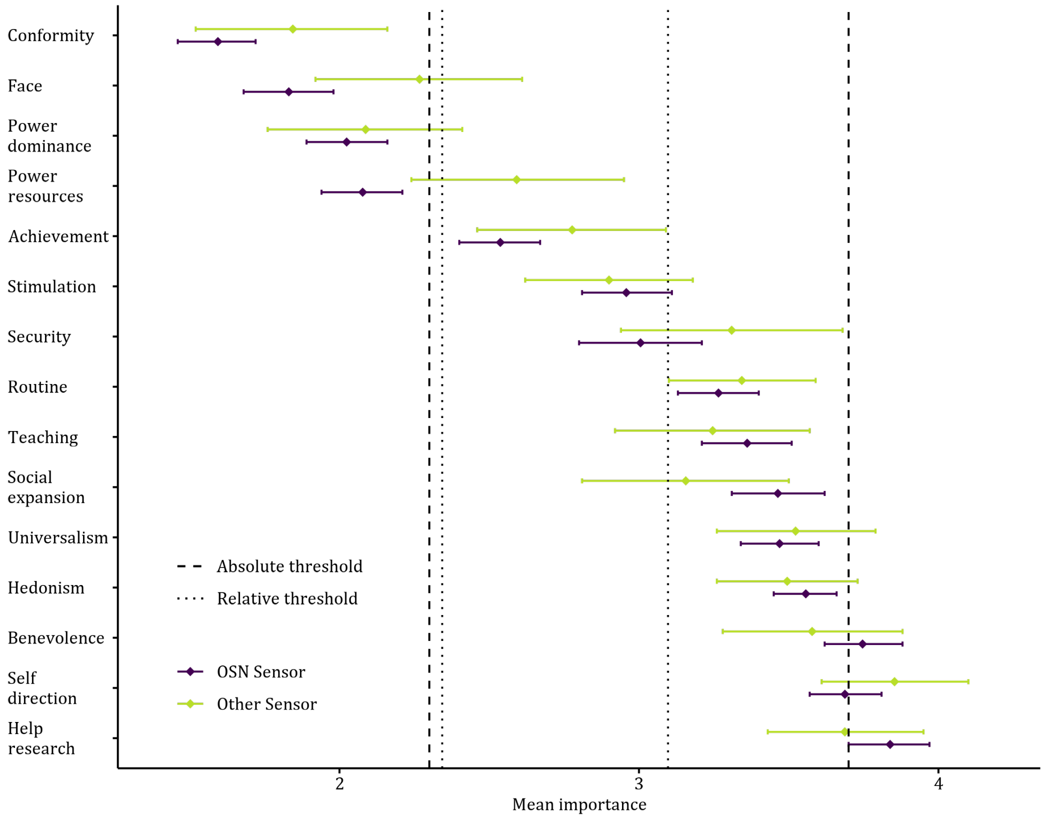

Figure 4. Mean and confidence intervals of motivational factors, grouped by people who contribute to OSN and people who contribute to other networks.

Table 4 illustrates the motivational factos in more detail. The results revealed that “help research” ranked among the most important motivators (p = 0.95 for H_0: true mean ≥ 3.7), whereas “routine” showed only moderate importance (p < 0.001). However, under relative thresholds, “routine” (p = 0.99 for H_0: true mean ≥ 3.08) appears as one of several key motivators, though it ranks last among these relatively influential factors. Thus, **H2**: “Helping with research is not among the main factors motivating individuals to operate a sensor for OSN”, is not supported by the data at hand, quite the opposite. Using absolute thresholds, **H3**: “Routine—being already engaged in a similar activity—is among the strongest motivators for operating a sensor for OSN” receives the same judgement. Yet, when using more relaxed standards for determining what is *strong* **H3** finds limited support.

When separating OpenSky contributors from those operating sensors for other networks, notable differences emerged, especially in the *face* and *power resources* categories. Mann–Whitney tests ($p < 0.05$) and OLS regressions controlling for demographics confirmed these as significant. With regards to **H2** and **H3** the results remain the same with the grouped data.

Item-level analysis showed that "I am interested in aviation" and "I want to contribute to independent, open-access data initiatives" were the strongest motivators (means of 4.25), while "I want to gain financially" was the least (2.24). The two items most often rated "irrelevant" were "I was requested to participate by somebody" and "I am required to take part in such a project," both reflecting minimal conformity motivation.

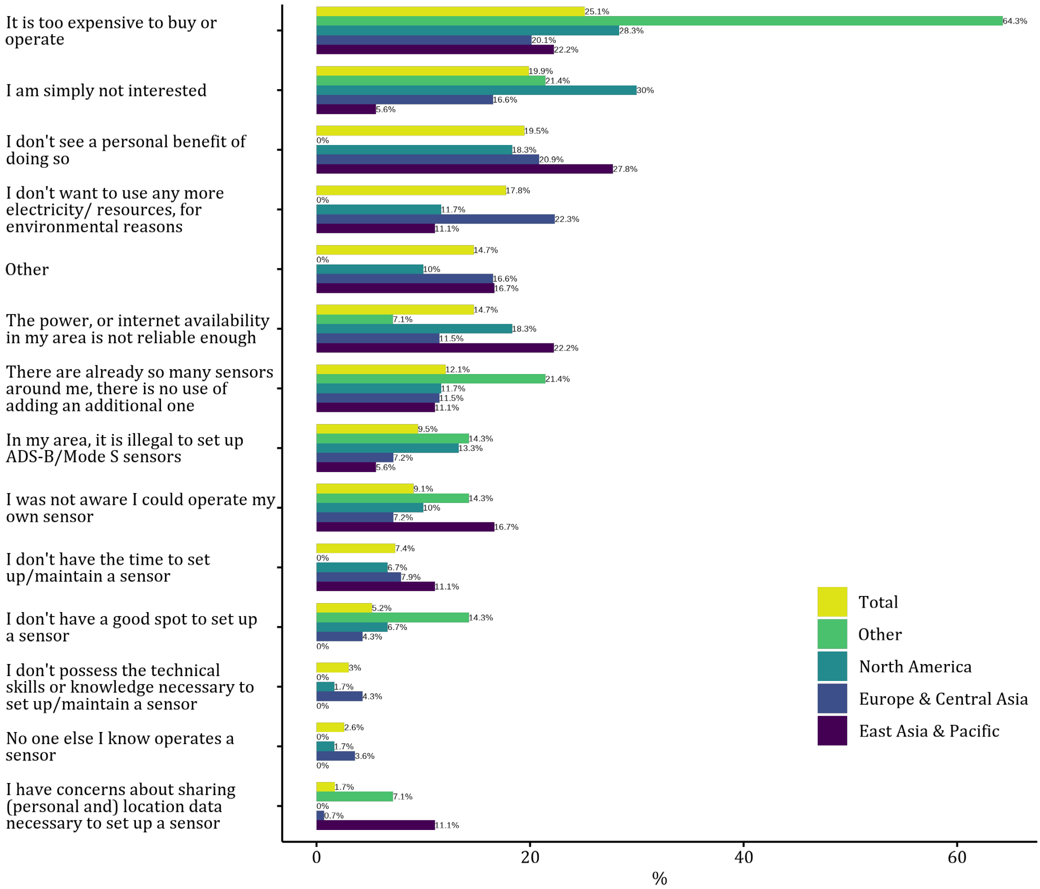

Figure 5. Reasons for not operating a sensor by region and in total.

5.3 Deterrent Factors

Among 375 reasons listed by 231 respondents without a sensor, financial cost emerged as the most prominent deterrent (see Fig. 5), lending support to **H4**. Cost concerns were salient across all regions but were particularly pronounced in the "other" region[3], where nearly 65% of respondents cited this as a barrier. In North America, lack of interest was the most frequently mentioned reason, whereas respondents in the East Asia & Pacific region tended to emphasize limited personal benefit. In Europe, more than 22% of respondents highlighted resource conservation or environmental considerations, making this the most notable deterrent in that region.

[3]This category includes MENA, Sub-Saharan Africa, Latin America, and South Asia

Open-ended "other" responses were few and did not deliver additional insights: several participants intended to set up a receiver but had not yet done so, while others cited broken or unreplaced hardware. Other comments broadly echoed predefined categories.

5.4 Discussion

With the exception of age, demographic findings fully supported **H1**. OpenSky participants are, on average, around 50 years old, meaning they are slightly older than participants in many other technology-based citizen science projects. Since category midpoints were used for the mean calculation this result is an approximation. Further, as there was no one younger than 18, the results are sensitive to the >75 midpoint. The chosen midpoint of 79.5 imposes an artificial maximum on this open-ended category and compresses its variability which leads to a downward bias as well as an underestimated standard deviation. However, because only 2.1% respondents fell into the >75 group, any downward bias in the calculated mean is expected to be small. If anything, OSN participants are slightly older than calculated, further supporting the finding. The significant gender imbalance was anticipated. As data is collected by sensors this fortunately doesn't impact data quality. The limited participation of individuals from the Global South is more consequential, as it affects network coverage and representativeness.

The motivational results did not support **H2** and only lent very limited support to **H3**. "Help research" was confirmed as a strong motivator, while "routine", though conceptually plausible and a somewhat strong motivator under relaxed thresholds, lacked empirical validity. The CFA results suggest that respondents may group motivational items differently from the predefined structure, indicating a need for theoretical refinement in future work. High inter-category correlations were also observed, consistent with Schwartz's (2012) notion of fluid value boundaries.

Assuming all relevant variables were observed, the motivational differences between OSN participants and non-participants suggest that structural or organizational characteristics specific to OSN attract individuals with a distinct motivational profile. In particular, OSN contributors appear to place less emphasis on social recognition and personal benefit than participants in other flight-tracking communities.

Finally, deterrence results clearly supported **H4**: the financial cost of equipment remains the main obstacle to active participation. Motivation alone is insufficient to drive engagement: practical and economic constraints clearly matter. Interestingly, obstacles identified as key in the literature, like perceived missing skills or time constraints, do not appear to be central for OSN. Addressing the identified obstacles could help the OSN expand its user base globally. Although the results are descriptive, regional differences indicate that certain outreach or engagement strategies may be more effective in some areas than others. These variations also suggest the possibility of trade-offs that should be considered when evaluating new approaches to user recruitment. Where feasible, targeted and region-sensitive strategies are likely to yield the greatest impact. Clearly, there are some obstacles, such as the lack of a suitable spot or the legality of sensor set-ups, which are impossible for OSN to alleviate.

Interestingly, while "too many sensors nearby" was a relevant deterrent, "poor coverage in my area" was only a moderate motivator, suggesting that awareness of network needs does not directly drive participation. Future recruitment strategies should therefore target both motivation and material accessibility.

6. Limitations

One limitation of the type of survey that was conducted is, that participants self-selected for the survey. This introduces certain bias in the data, which is almost inescapable with the given online setup [58]. The fact that helping research is identified as the most important motivational factor might have been influenced by such a self-selection bias. Specifically, it could be assumed that the general predisposition toward responding to surveys is higher among people interested in research than those not. The raffle that was intended to motivate more people to participate might have helped balance out the rate between active and passive members a bit, but in the end, the response rate among the active members was still higher.

Furthermore, while this study focused on describing motivational patterns at an aggregate level, it did not analyse how these motivations or deterrents might vary across demographic subgroups or interact with structural factors such as education, income, or employment status. Given that such variables are often correlated, future research could employ multi-factor analytical techniques to disentangle the partial contribution of each predictor. This would allow for a more nuanced understanding of whether demographic heterogeneity meaningfully shapes the motivational configuration of SCS contributors.

7. Conclusion and Recommendations

The survey conducted among OpenSky Network members offered valuable insight into who participates in sensor-based citizen science projects and why. In doing so, it advances the citizen-science literature by providing empirical evidence on participation dynamics in SCS projects, an area that has received comparatively little attention before. The results confirm that OSN's active community largely consists of well-educated, above-median-income males from Western countries. Despite OSN's digital nature, the approximate average participant age was around 50 years, contrary to expectations that technology-driven citizen science attracts younger individuals.

Motivational analysis revealed that "help research" was the most important factor driving participation. This finding is striking, as OSN contributors are not aware of any single, clearly defined research goal but instead, their data are made openly available for scientific use across domains. This is further supported by the item level results, which underscores the appeal of contributing to open, independent research. Routine engagement, such as maintaining existing aviation-related hobbies, was also relevant but measured less reliably, suggesting that the underlying construct may require further refinement.

The deterrence analysis identified *financial cost* as the strongest barrier preventing individuals from operating a sensor. While this has not been reported as a major obstacle in earlier citizen-science studies, the difference is expected. Much of the prior literature has examined projects that either provide equipment to participants or require no material investment at all. SCS networks such as OSN, however, depend on up-front investments, making financial barriers far more salient. By demonstrating this distinction, the present study contributes new insights to citizen-science research, particularly regarding the structural obstacles faced by infrastructure-dependent projects.

The survey also highlighted regional disparities in participation: while the network's presence remains concentrated in Europe and North America, engagement is very limited in the Global South. This pattern likely reflects both economic and infrastructural inequalities. Importantly, the identified financial barrier appeared most acute the regions with limited network coverage. In contrast, in wealthier regions such as Europe and North America, disinterest and environmental considerations were more frequently mentioned as reasons for non-participation. To increase the OSNs footprint in underserved regions, the network could collaborate with local educational institutions and NGOs to distribute low cost or loan based equipment, and/or introduce a simple, regionally adapted subsidy program allowing applicants from areas with little to no coverage to obtain sensors at reduced cost or for free. In addition to material support programs, the network might consider region-specific outreach efforts conducted in local languages and tailored to locally relevant use cases, which could help increase visibility and clarify the practical value of participation.

Finally, results from both motivational and deterrent analyses point to a broader lesson for SCS and specifically OSN: while interest in the topic and financial aspects matter, maintaining the network's *open-access, independent character* is a central motivational driver for contributors. The most highly rated individual motivation - "I want to contribute to independent, open-access data initiatives" - emphasizes that current participants value openness and trust highly. Strengthening this message could help OSN and the researchers, who use its data, sustain growth and broaden participation in the long term. To do so, OSN could explore making research outcomes based on community generated data more visible and accessible. For example, through short, non technical summaries or blog-style updates on the network website. Highlighting how community-driven sensing supports academic research, aviation transparency, and global-scale environmental insights may further reinforce the project's societal relevance. Featuring contributor stories, particularly from underrepresented regions, could additionally humanize the network and provide relatable entry points for prospective participants.

Taken together, emphasizing openness while offering accessible insights into the real world impact of community contributions could help sustain long term engagement and broaden participation across diverse regions. As a next step, we propose establishing a small working group to review and prioritize these potential measures in light of the network's financial and human resource constraints. This group should also consider whether trade-offs between different strategies could emerge in cases where initiatives designed to attract certain regional or motivational profiles could inadvertently reduce engagement among others.

Author contributions

- First Author: Data Curation, Formal Analysis, Investigation, Methodology, Software, Supervision, Validation, Visualization, Writing (Original Thesis)
- Second Author: Conceptualization, Supervision, Survey Planning, Writing - Second Draft
- Third Author: Conceptualization, Supervision, Writing - Second Draft
- Fourth Author: Conceptualization, Supervision, Project Administration, Resources, Survey Planning, Visualization, Writing - First Draft

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Open data statement

The full R notebook for data analysis and figure generation is available at https://github.com/openskynetwork/crowdsourcing-survey. For reasons of individual anonymity, data privacy, and ethics requirements, individual survey responses cannot be made available.

Reproducibility statement

The source code for the statistical analysis and all figures is available at https://github.com/openskynetwork/crowdsourcing-survey. Individual survey responses are not included due to data privacy and ethics requirements.

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Appendix 1. Questionnaire

Informed Consent Form

Welcome to the OpenSky Survey!

This survey is conducted as a part of a master's thesis project at ETH Zurich and the Cyber-Defence Campus. The goal is to understand the makeup of the OpenSky Network (OSN) and the reasons why members of the network choose to participate actively as sensor operators or remain passive members. Gaining these insights can help enhance engagement and data coverage within OSN and similar networks, supporting broader public access to aviation and other data. Participation is voluntary, and you may withdraw at any time. To participate, you must have an OSN user account and be at least 18 years old. At the end of the survey, you may choose to leave your e-mail address to participate in a price draw for a new ADS-B/Mode S sensor. The survey takes around 5-10 minutes to complete. The survey will ask for your OSN username. This is simply to confirm your membership and, if you operate a sensor, link your responses to sensor activity data. This helps us better understand the network's patterns. Please note that this does not involve accessing or analyzing your personal activity on the OSN in any way. In accordance with the ethical guidelines of ETH Zurich, your information will be treated strictly confidentially, and the identifying information will be removed before data analysis. No conclusions will be drawn about your person at any time. Please read the information above carefully. By clicking "Next" you consent to participate in the survey. We thank you in advance for taking your time to participate! If you have any questions about the study, please contact jinauen@student.ethz.ch anytime. This study was reviewed and approved by the ETH Zurich Ethics Committee under application number 24 ETHICS-403. The secretariat of the ETH Zurich Ethics Committee is available to help you with complaints in connection with your participation in the study. Contact: ethics@sl.ethz.ch or 0041 44 632 85 72.

Q1

What is your OpenSky username? Please make sure the spelling is correct.

Q2

How old are you?

- younger than 18 (1)
- 18-24 (2)
- 25-34 (3)
- 35-44 (4)
- 45-54 (5)
- 55-64 (6)
- 65-74 (7)
- older than 75 (8)

Q3

What is your gender?

- Male (1)
- Female (2)
- Non-binary / third gender (3)

- Prefer not to say (4)

Q4
What country do you live in? Please enter and select the country's English name below.

Q5
What type of area do you live in?

- Rural (Countryside) (1)
- Urban (City) (2)
- Suburb (3)

Q6
How much is the area where you live influenced by the presence of an airport (e.g., through noise, visual presence, ...)?

- Very much (1)
- Somewhat (2)
- Not much (3)
- Not at all (7)

Q7
What is your highest completed level of education?

- No education (1)
- Primary education or less (e.g., years 1-6, ...) (3)
- Lower secondary education (e.g., years 7-9, middle school, ...) (4)
- Higher secondary education (e.g., high school, basic vocational training, ...) (5)
- Short tertiary education (e.g., extended professional training, ...) (6)
- Bachelor's degree or equivalent (e.g., undergraduate, licence, ...) (7)
- Master's degree or equivalent (8)
- Doctoral degree or equivalent (9)

Q8
What is your current primary occupation?

- Unemployed (1)
- Student (2)
- Self-employed (4)
- Part-time employed (5)
- Full-time employed (6)
- Retired (7)
- Other (8)

Q9

What sector are you primarily occupied in?

- Private business or industry (1)
- Academia (2)
- Other public or government insitution (3)
- Private non-profit organization (4)
- Other (5)

Q10

Is your occupation in any way related to aviation?

- Yes (1)
- No (2)

Q11

What is your income group?

Below you see a scale from 1 to 5. On this scale, 1 represents households in the lowest 20% of income in your country, while 5 represents those in the highest 20%. Please indicate what group you think your household belongs to by adjusting the slider. Consider all wages, salaries, pensions and other kinds of income of your household when doing this.

Slider with levels 1-5

Q12

Do you own and operate a ADS-B/Mode S Sensor that contributes to OpenSky?

- Yes (1)
- No (2)
- I operate a sensor, but it doesn't contribute to OpenSky (3)

Q13.1

What are the main reasons you do not own a sensor? Select up to 3 responses. (List randomized for respondents)

- It is too expensive to buy or operate (1)
- I don't have the time to set up/maintain a sensor (2)
- I don't possess the technical skills or knowledge necessary to set up/maintain a sensor (3)
- I have concerns about sharing (personal and) location data necessary to set up a sensor (4)
- I was not aware I could operate my own sensor (5)
- There are already so many sensors around me, there is no use of adding an additional one (6)
- I don't see a personal benefit of doing so (7)
- The power, or internet availability in my area is not reliable enough (8)
- I don't have a good spot to set up a sensor (9)

- I am simply not interested (10)
- I don't want to use any more electricity/resources, for environmental reasons (11)
- In my area, it is illegal to set up ADS-B/Mode S sensors (12)
- No one else I know operates a sensor (13)
- Other (please indicate the reason) (14)

Q13.2
Motivations for operating a Sensor.

This part of the survey explores your motivation for maintaining a sensor and participating in the OpenSky or a similar Network. Using a scale from 1 (not important) to 5 (very important), please rate how important each of the following reasons is for your participation. We encourage you to use the full range of the scale when answering. If a statement doesn't apply to you, feel free to select "irrelevant."

Options provided to users shown in Table 3.

Q14
If there is anything you would like to add to your responses, feel free to leave a comment below.

Table 3. Motivational items and their corresponding categories.

Category	Item Nr	Description
Self-direction	1	I want to learn about aviation, airspace security, or similar.
	2	I am interested in aviation.
	3	I contribute because it gives me access to information that I need.
Stimulation	4	I want to do something new.
	5	I want to break away from my routine.
Routine	6	Maintaining an ADS-B/MODE-S sensor is related to another hobby I have (e.g., plane spotting).
	7	I was maintaining an ADS-B/MODE-S sensor anyway (e.g., as part of my job/studies).
	8	I'm a regular participant in citizen science, crowdsourcing, or similar projects.
Hedonism	9	I enjoy maintaining an ADS-B/MODE-S sensor.
	10	I enjoy seeing my own contributions appear on the map and/or my personal dashboard.
	11	I am passionate about the OpenSky Network.
Achievement	12	I want to advance my career.
	13	It's an opportunity to perform better than others.
	14	I want to provide sensor coverage in an area that is otherwise badly/not covered.
Power resources	15	I want to gain financially.
	16	I expect something in return (e.g., general data access, newsletter, personal dashboard, ...).
Attention test	17	If you are actively reading this, please select five.
Power dominance	18	I want to gain recognition and status.
	19	Providing OpenSky with data makes me feel important.
Face	20	I want to enhance my reputation.
	21	Other people think positively about my contribution to OpenSky.
Social expansion	22	I want to be part of this volunteer community.
	23	I want to feel part of something worthwhile.
Security	24	I want to keep myself secure and healthy.
	25	I want to live in secure surroundings.
Conformity	26	I am required to take part in such a project.
	27	I was requested to participate by somebody.
	28	Other people I know are participating.
Benevolence	29	It is a good thing to do.
	30	I want to contribute to my community.
Universalism social	31	I want to improve our society.
	32	I want to contribute to independent, open-access data initiatives.
	33	I want to raise public awareness about aviation.
	34	I want to protect the environment.
Help with research	35	I want to contribute to the knowledge about aviation.
	36	I want to contribute to scientific research.
Teaching	37	I want to provide learning opportunities to others.
	38	I want to share my knowledge and experience.